APPENDIX A

Projected Fertilizer Sales from 1951 – 2002

Provided by Dr. Gordon Johnson

Oklahoma

Year	State Phosphorus as P2O5 x1000*	Projected P2O5 sales for counties (tons) Adair	Cherokee	Delaware	Sequoyah
1951	25	615	138	399	0
1952	30	596	147	381	0
1953	23	623	134	406	0
1954	21	630	131	413	0
1955	19	638	127	420	0
1956	21	630	131	413	0
1957	18	642	125	423	0
1958	18	642	125	423	0
1959	25	615	138	399	0
1960	26	611	140	395	0
1961	34	581	154	367	0
1962	45	539	174	329	36
1963	49	524	181	315	52
1964	54	505	190	297	72
1965	61	478	203	273	100
1966	69	448	217	245	132
1967	79	410	235	210	172
1968	76	421	230	220	160
1969	85	387	246	189	196
1970	90	368	255	171	216
1971	98	338	269	143	248
1972	97	341	268	147	244
1973	110	292	291	101	296
1974	106	307	284	115	280
1975	95	349	264	154	236
1976	105	311	282	119	276
1977	116	269	302	80	320
1978	87	379	250	182	204
1979	115	273	300	84	316
1980	115	273	300	84	316
1981	109	296	289	105	292
1982	98	338	269	143	248
1983	97	341	268	147	244
1984	99	334	271	140	252
1985	104	315	280	122	272
1986	90	368	255	171	216
1987	96	345	266	150	240
1988	96	345	266	150	240
1989	104	315	280	122	272
1990	91	364	257	168	220

Year	State Phosphorus as P2O5 x1000*	Projected P2O5 sales for counties (tons) Adair	Cherokee	Delaware	Sequoyah
1991	77	417	232	217	164
1992	76.9	418	231	217	164
1993	83.8	392	244	193	191
1994	90.6	366	256	169	218
1995	85.8	384	247	186	199
1996	80.2	405	237	205	177
1997	77	417	232	217	164
1998	79	410	235	210	172
1999	62.7	472	206	267	107
2000	68	452	215	248	128
2001	56.1	497	194	290	80
2002	75	425	228	224	156
2003	46	535	176	325	40
2004	56	498	193	291	79
2005	53	510	188	302	66
2006	49	523	182	314	53
2007	46	536	175	326	39
2008	42	549	169	338	25

*From files used to print Oklahoma Soil Fertility Handbook; from OSDA reports.

Shaded cells are based on State totals projected from sales since 1980.

Arkansas

Fertilizer P2O5 and N Tonnage for Arkansas and Selected Counties

Year	Benton Total tons P2O5	Washington Total tons P2O5	Benton Total tons N	Washington Total tons N
1951	23	12	43	21
1952	38	20	72	35
1953	53	28	100	49
1954	68	36	129	62
1955	83	44	157	76
1956	98	52	185	90
1957	113	60	214	104
1958	128	68	242	117
1959	143	76	270	131
1960	158	84	299	145
1961	173	92	327	159
1962	188	100	355	172
1963	203	108	384	186
1964	218	116	412	200
1965	233	124	440	214
1966	248	132	469	227
1967	263	140	497	241
1968	278	148	526	255
1969	293	156	554	269
1970	308	164	582	282
1971	322	172	611	296
1972	337	180	639	310
1973	352	188	667	324
1974	367	196	696	337
1975	382	204	724	351
1976	397	212	752	365
1977	412	220	781	379
1978	427	228	809	392
1979	442	236	837	406
1980	457	244	866	420
1981	472	252	894	434
1982	487	260	923	448
1983	502	268	951	461
1984	517	276	979	475
1985	532	284	1,008	489
1986	547	292	1,036	503
1987	562	300	1,064	516
1988	577	308	1,093	530
1989	592	316	1,121	544
1990	607	324	1,149	558
1991	622	331	1,178	571
1992	962	450	1,001	370

Fertilizer P2O5 and N Tonnage for Arkansas and Selected Counties

Year	Benton	Washington	Benton	Washington
	Total tons P2O5		Total tons N	
1993	858	481	887	388
1994	837	466	984	443
1995	816	451	1,081	499
1996	796	435	1,179	554
1997	591	489	717	379
1998	754	405	1,373	664
1999	734	390	1,470	720
2000	713	375	1,567	775
2001	692	360	1,664	830
2002	800	363	2,339	1,332
2003	651	330	1,858	941
2004	630	315	1,955	996
2005	582	259	1,823	795

Values in shaded cells were estimated from tonnage reports.
Values in shaded cells were estimated from regression of total tonnage and time, followed by fraction of total that is P2O5 or N.

APPENDIX B

Golf Courses in the Illinois River Watershed

Oklahoma

Cherokee Trails Golf Course – 22706 South 504 Road Hwy 62, Tahlequah, OK 74441, (918)458-4294, semi-private, 9 hole

Cherry Springs Golf Club – 700 E Ballentine Rd, Tahlequah, OK 74464, (918)456-5100, public, 18 hole

Tahlequah City Golf Course – Bryant Rd, Tahlequah, OK 74464, (918)456-3761, public, 9 hole

Deer Valley Golf Club – Hwy 10, Kansas, OK 74347, (918)597-3636, private, 9 hole

Section 1.01 Arkansas

Lost Springs Golf & Athletic Club – 3024 N 22nd St, Rogers, AR 72756, (501)631-9988, private, 18 hole

Pinnacle Country Club – 3 Clubhouse Dr, Rogers, AR 72758, (501)273-0555, private, 18 hole

Prairie Creek Country Club – Hwy 12 E & Country Club Rd, Rogers, AR 72757, (501)925-2414, semi-private, 18 hole

Shadow Valley Country Club – 7001 Shadow Valley Road, Rogers, AR 72758, (479) 203-0000, private, 18 hole

Brush Creek Golf Course – 6220 Har Ber Ave, Springdale, AR 72762, (501)750-0606, public, 9 hole

Springdale Country Club – 4705 S Thompson, Springdale, AR 72764, (501)751-5185, private, 18 hole

Dawn Hill Golf & Racquet Club – Dawn Hill Rd, Siloam Springs, AR 72761, (800)423-3786, resort, 18 hole

Siloam Springs Country Club – 801 N Country Club Rd, Siloam Springs, AR 72761, (501)524-4269, semi-private, 9 hole

Links at Bentonville Golf & Athletic Club – 2101 SE Hilton Head Dr, Bentonville, AR 72712, (479)271-0163, public, 9 hole

Fayetteville Country Club – 3335 Country Club Dr, Fayetteville, AR 72701, (501)442-5112, private, 18 hole

Paradise Valley – 3728 Old Missouri Rd, Fayetteville, AR 72703, (501)521-5841, private, 18 hole

Razorback Park Golf Course – 2514 W Lori Dr, Fayetteville, AR 72704, (501)443-5862, public, 18 hole

Stonebridge Meadows Golf Club – 3495 E Goff Farms Rd, Fayetteville, AR 72701, (479)571-3673, public, 18 hole

Lakeside Village Golf Course – 200 Village Lake Drive, Fayetteville, AR 72703, (479)442-7748, public, 9 hole

The Blessings Country Club – 5826 Clear Creek Blvd, Fayetteville, AR 72704, (479)444-6330, private, 18 hole

The Creeks Public Links – 190 S Hwy 112, Cave Springs, AR 72718, (501)248-1000, public, 18 hole

APPENDIX C

Industrial Sources

Facility Descriptions and Average Phosphorus Inputs

Provided by Dr. Bernie Engel

Facility Name	Description
Allen Canning Co	Spinach and other greens, green beans, and dry-pack beans are processed and canned.
Blaylock Company	Poultry product is ground, frozen, stored, and shipped to pet food manufacturing facilities
Cargill, Inc.	Turkey slaughter, deboning, and further processing
Cintas Corporation	Laundering and processing of industrial uniforms, shop towels, mats, and mops
D. B. Foods, Inc	Eggs are broken, processed, frozen, and shipped to another facility to be dehydrated.
D. B. Foods, Inc.	Eggs are broken, processed, frozen, and shipped to another facility to be dehydrated
Danaher Tool Group	Forging, stamping, broaching, grinding, and electroplating wrenches
George's Further Processing	Raw chicken is deboned and shipped out fresh. Some is marinated, cooked, etc., and shipped out
George's, Inc.	Poultry slaughter, chilling, cutting, packing, and shipping.
J. B. Hunt Transport, Inc	Truck and trailer maintenance, including washing, fueling, mechanical and wreck repair.
Pappas Foods, L.L.C.	Fruit is delivered, pressed, pasteurized, and stored in refrigerated tanks. Various fruit ingredients are blended and filtered. Bottles are filled, packed, palletized, and shipped. A non-fruit (sports drink) is also prepared at this facility. The only fresh fruit processed is grapes and cranberries. All other fruit comes in as a prepared concentrate
Sonstegard Foods Inc. of Arkansas	Eggs are broken, processed, frozen, and shipped to another facility to be dehydrated
Superior Linen Service	Washing and drying rental linen - napkins, table cloths, towels, sheets, pillow cases, floor mats, etc.
Triple T Foods, Inc.	Poultry products are ground and frozen, then shipped off for use as animal feed
Tyson Foods, Inc. - Berry St.	Chickens are unloaded, killed, scalded, picked, eviscerated, chilled, weighed, cut up, breaded, cooked, frozen, packed, weighed, boxed, stored, and shipped.
Tyson Foods, Inc. - Hog Trailer Wash	Washing of hog trailers
Tyson Foods, Inc. - Randall Rd.	Chickens are received, slaughtered, eviscerated, packed, frozen, and shipped
Tyson Research & Technology	Further processing of products made from chicken, research and development

Facility Name	P ave (kg/d)
Allen Canning Co	5.35
Allen Canning Co	36.64
Blaylock Company	1.28
Cargill, Inc.	53.90
Cintas Corporation	3.47
D. B. Foods, Inc	7.89
Danaher Tool Group	13.46
Danaher Tool Group	3.05
George's Debone	13.83
George's Further Processing	23.60
George's, Inc.	52.39
J. B. Hunt Transport, Inc	0.39
J. B. Hunt Transport, Inc	0.19
Monark Egg	5.54
Midcentral Egg	2.89
Pappas Foods, L.L.C.	1.84
Sonstegard Foods Inc. of Arkansas	0.00
Superior Linen Service	1.43
Triple T Foods, Inc.	1.79
Tyson Foods, Inc. - Berry St.	110.69
Tyson Foods, Inc. - Hog Trailer Wash	6.58
Tyson Foods, Inc. - Randall Rd.	56.14
Tyson Research & Technology	2.76
Total	**405.07**

APPENDIX D

Pounds of Nutrients Removed by Harvested Crops

Year	Nutrient (lb)	Corn for Grain	Sorghum for Grain	Wheat for Grain	Oats	Soybeans for Beans
1949	N	532,012	6,213	43,669	188,881	5,481
	P	101,569	1,107	8,247	36,499	561
	K	111,921	1,287	9,242	41,885	1,287
1954	N	21,728	2,090	35,213	342,784	9,510
	P	4,148	372	6,650	62,530	974
	K	4,571	433	7,440	76,013	2,232
1959	N	247,431	52,146	61,793	67,045	48,927
	P	47,238	9,292	11,669	12,230	5,012
	K	52,052	10,799	13,057	14,867	11,485
1964	N	43,881	13,148	74,763	-	82,142
	P	8,378	2,343	14,119	-	8,414
	K	9,231	2,723	15,797	-	19,282
1969	N	19,810	32,167	49,149	-	95,045
	P	3,782	5,732	9,281	-	9,736
	K	4,167	6,662	10,385	-	22,310
1974	N	10,422	18,865	35,140	-	103,845
	P	1,990	3,361	6,636	-	10,637
	K	2,193	3,907	7,425	-	24,376
1978	N	12,818	31,033	67,179	-	170,065
	P	2,447	5,530	12,686	-	17,420
	K	2,696	6,427	14,195	-	39,920
1982	N	5,791	16,184	151,071	-	221,323
	P	1,106	2,884	28,529	-	22,671
	K	1,218	3,352	31,921	-	51,952
1987	N	0	15,664	26,020	-	182,735
	P	0	2,791	9,194	-	18,718
	K	0	3,244	10,287	-	42,894
1992	N	0	2,308	48,866	-	126,606
	P	0	411	9,228	-	12,969
	K	0	478	10,325	-	29,719
1997	N	15,405	1,892	48,206	-	104,954
	P	2,941	337	9,103	-	10,751
	K	3,241	392	10,186	-	24,636
2002	N	21,378	1,733	95,512	-	63,993
	P	4,081	309	18,037	-	6,555
	K	4,497	359	20,182	-	15,021

Appendix C

River Phosphorus Concentrations vs. Poultry House Density

The analyses described in this appendix were a collaborative effort of Dr. Roger Olsen, Dr. Tim Cox, and Dr. Bernard Engel. Dr. Cox prepared the text contained in this appendix.

Objectives

The primary objective of this analysis was to investigate for causal links between selected sub-basin characteristics and total phosphorus concentrations in tributaries of the Illinois River. In particular, the impacts of poultry house presence on stream water quality were investigated. A secondary objective was to develop the basis for a simple empirical predictive tool to assist in watershed management.

Methods

This work involved linear regression analyses of data collected as part of the small tributary sampling program in the basin. Data were collected for both highflow and baseflow conditions throughout two summer periods (2005 and 2006). Data were collected from a total of fourteen sampling locations in small tributaries throughout the basin that covered a range of drainage area size and landuse characteristics. In particular, a representative range of poultry house presence (from no presence to highly active presence) was included in the sampling program. Further details of this sampling program are provided in Olsen (2008).

Regression analyses were performed for measured total phosphorus concentrations as a function of a range of hypothesized potential predictor variables, including poultry house densities in local drainage areas. Table 1 summarizes the predictor variables included in the analysis. Predictor variables were generally quantified using a combination of GIS mapping, aerial photographs, and field reconnaissance. Poultry house densities were determined by first identifying and locating potential poultry houses using up-to-date aerial photography of the watershed. These houses were then confirmed through field reconnaissance and categorized as either "active", "temporarily inactive", or "abandoned". The house locations were then mapped in GIS and densities were calculated as the number of houses in the targeted sub-basin divided by the area of the sub-basin (Fisher, 2008). Only active houses were included in the "active house density - AHD" calculations while all houses (active + inactive + abandoned) were included in the "total house density – THD" calculations. Soil Conservation Service Curve Numbers (SCS CN) were estimated by first intersecting GIS layers of soil hydrologic type (A – D) and landuse category. Table 2 of the USDA Technical Release-55 ("Urban Hydrology for Small Watersheds") was then used to assign curve numbers to each intersection area of each sub-basin. Finally, these values were used to calculate area-weighted average curve numbers for each sub-basin. Other parameters listed in 1 were calculated using standard GIS mapping and calculation methods.

High flow and baseflow data were separated for this analysis. Total phosphorus concentration data were pooled in three ways: 2005 only, 2006 only, and combined 2005 – 2006. For the high flow analysis, flow-composited samples from each event were averaged for each time period pool for each sampling station. In other words, a single average value was generated for each pool and each station. The flow-weighted averaging method used here applied weightings to each event based on the relative size of the event. Flow-weighted averages were calculated as:

$$TP_{avg} = \frac{1}{\sum_{n=1}^{numEvents} Vol_i} \sum_{n=1}^{numEvents} EMC_i Vol_i$$

where TP_{avg} = the flow-weighted average phosphorus concentration, i = index for a given sampled storm event, numEvents = number of sampled storm events, Vol_i = total runoff volume for storm event i, and EMC_i = measured event mean phosphorus concentration for event i. In this way, the values assigned to each station better capture the relationships between total mass *loads* and sub-basin characteristics. Thus, a small runoff event that results in high phosphorus concentrations is weighted less in the calculations than a large event which results in lower concentrations to reflect the relative mass loads of the two events.

Straight averaging across sampling events was used for the baseflow data.

Two of the sampling stations, Site HFS 04 and HFS 22, were excluded from the statistical analysis described here due to the presence of point sources within the station sub-basins. Stream water quality at these two sites is dominated by effluent from the City of Siloam Springs wastewater treatment plant and the City of Lincoln wastewater treatment plant, respectively. These sites were sampled to provide information on the mass loads contributed by these types of facilities but are not appropriate for inclusion in the analysis described here. Additionally, 2006 data from HFS 14 were excluded from the analysis. While this site was a verified reference site in 2005 (no poultry activity in the sub-basin), poultry waste spreading was observed on a field immediately upstream of the sampling site in 2006. Therefore, the original landuse designation (forested) and poultry house density (0 houses/mi.) were not valid in 2006 and the data collected during this sampling period were omitted from the analysis.

Microsoft Excel was used to calculate correlation coefficients (R^2 values) and significance levels (p values) for each pairing of predictor variable and total phosphorus concentration. A statistically significant correlation was defined as one in which $p \leq 0.05$ (95% significance level).

Results and Discussion

Table 2 summarizes the results of the regression analysis. Graphical results of two sets of regressed data with high correlation coefficients, high significance, and good data spread are shown in Figures 1 and 2.

As can be seen, sub-basin poultry house densities, in a variety of forms, appear to be strong predictors of stream total phosphorus concentration. This is particularly true when the 2005 and 2006 data are pooled and a more comprehensive data set is formed. For the combined 2005-06 data sets, all 6 of the poultry house density predictor variable forms are shown to be significantly and positively correlated with total phosphorus concentrations in the receiving streams during highflow events. Overall, 21 out the 36 TP vs. poultry density regressions show significant and positive correlations. The strongest and most convincing correlations appear to be for the pooled 2005 – 06 phosphorus concentrations vs. total and active poultry house densities within a 2 mile buffered drainage area (Figures 1 and 2). These results indicate that poultry house density could be used as a predictor of stream phosphorus concentrations in this watershed. Additionally, the relationships established here could be used to guide watershed management decisions.

Septic tank density is also shown to be a statistically significant predictor of stream phosphorus concentration for most of the data combinations. However, these correlations are not generally as strong as those associated with poultry house density, particularly for high flow conditions. Additionally, a strong cross correlation is observed between septic tanks and total poultry house density within the 2 mile buffered area (see Figure 3). In other words, in areas with high poultry house development, human dwellings are also relatively high. This is not unexpected. Finally, an independent analysis of the total phosphorus loading expected from septic tanks in the watershed has shown these contributions to be negligible relative to the total mass loading in the systems (see Appendix G). These factors lead us to conclude that a true causal relationship between septic tanks and stream phosphorus concentration does not exist. Rather, the perceived correlation between these variables is simply an artifact of the cross-correlation between residential dwellings and poultry house presence.

The Soil Conservation Service Curve Number (SCS CN) is shown to be a significant predictor of the 2005 baseflow TP concentrations (positive correlation). Similarly, the percent of the sub-basin stream length with riparian buffers is shown to be a significant predictor of 2006 highflow TP concentrations (negative correlation). Both of these parameters are significantly correlated with only one of the six TP datasets, and neither is significantly correlated with the most comprehensive dataset (pooled 2005-06 data). Therefore, we conclude that these parameters are, at best, weak predictors of stream phosphorus concentration.

Table 1
Potential Total Phosphorus Predictor Variables

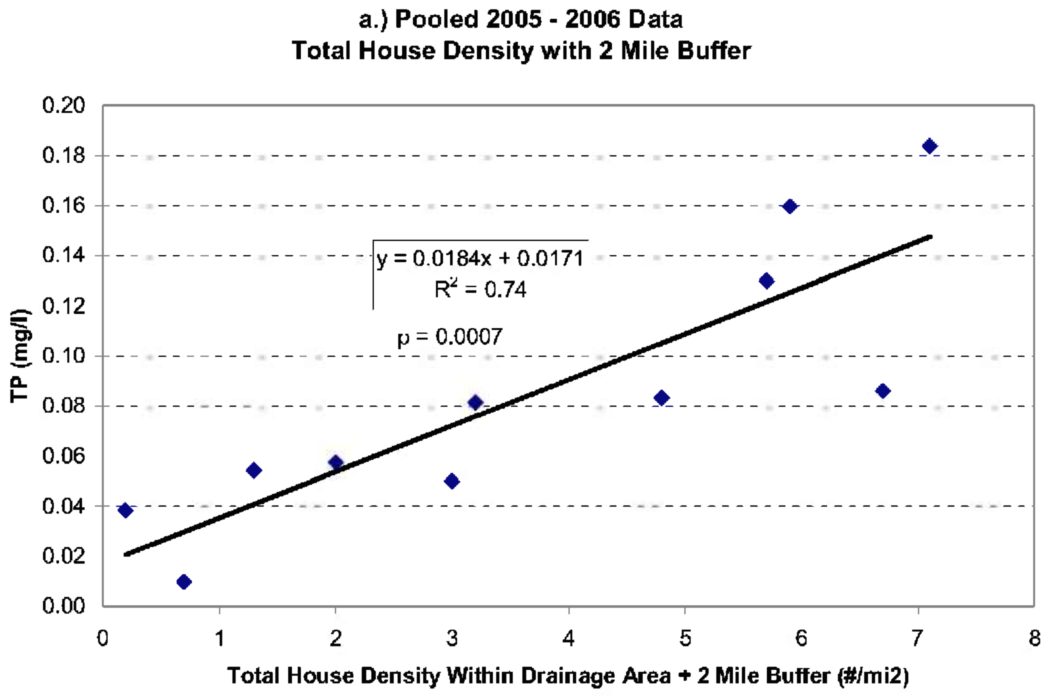
Variable	*Description*	*Rationale*
Total House Density (THD)	density (houses per mi^2) of all identified poultry houses, including inactive houses, in sub-basin	poultry waste is spread on fields in vicinity of poultry houses *(expected positive correlation)*
Active House Density (AHD)	density (houses per mi^2) of all identified active poultry houses in sub-basin	“”
THD – 1 mile buffered	density (houses per mi^2) of all identified poultry houses in sub-basin plus 1 mile perimeter buffer	tributary water quality may be impacted by poultry houses a short distance outside of sub-basin (waste transported from a house outside the basin to a field inside the basin) *(expected positive correlation)*
AHD – 1 mile buffered	density (houses per mi^2) of all identified active poultry houses in sub-basin plus 1 mile perimeter buffer	“”

THD – 2 mile buffered	density (houses per mi^2) of all identified poultry houses in sub-basin plus 2 mile perimeter buffer	approximately 80% of poultry waste is spread on fields within 2 miles of poultry house (Fisher, 2008) *(expected positive correlation)*
AHD – 2 mile buffered	density (houses per mi^2) of all identified active poultry houses in sub-basin plus 2 mile perimeter buffer	""
SCS CN	Soil Conservation Service Curve Number	sub-basins with varying runoff potential may differ in their impact on receiving stream water quality
Septic Tank Density	estimated density (tanks per mi^2) of septic tanks in sub-basin	leaching from septic tanks may carry a significant phosphorus load *(expected positive correlation)*
% Pasture	percent of pasture in sub-basin	amount of pasture in a sub-basin can serve as a surrogate for agricultural activity which may be a good predictor of stream phosphorus concentration *(expected positive correlation)*
% Riparian Buffer	percent of stream length in sub-basin that is buffered by forest	riparian buffers can filter nutrients from runoff prior to entering streams *(expected negative correlation)*
Median Distance to Chicken Houses	median of distances (mi) from poultry houses in the sub-basin to the sampling site	poultry houses closer to the stream may have a greater impact on water quality than those further away *(expected negative correlation)*

Table 2
Regression Analysis Results Summary[1]

	2005 Highflow	2005 Baseflow	2006 Highflow	2006 Baseflow	2005 – 06 Highflow	2005 – 06 Baseflow
THD	0.64	0.86	0.14	0.66	0.76	0.68
AHD	0.32	0.73	0.26	0.49	0.56	0.47
THD – 1 mi	0.28	0.63	0.39	0.31	0.65	0.3
AHD – 1 mi	0.13	0.42	0.49	0.18	0.49	0.19
THD – 2 mi	0.48	0.63	0.27	0.35	0.74	0.36
AHD – 2 mi	0.49	0.64	0.28	0.33	0.74	0.36
SCS CN	0.18	0.43	0.14	0.40	0.23	0.27
Septic Tanks	0.48	0.52	0.15	0.57	0.37	0.41
% Pasture	0.13	0.13	0.09	0.01	0.12	0.01
% Rip. Buff.	0.03	0.09	0.49	0.19	0.18	0.12
Med. Dist. CH	0.11	0.07	-0.25	0.01	0.04	0.001

1 = statistically significant correlations ($p \leq 0.05$) indicated by highlighting



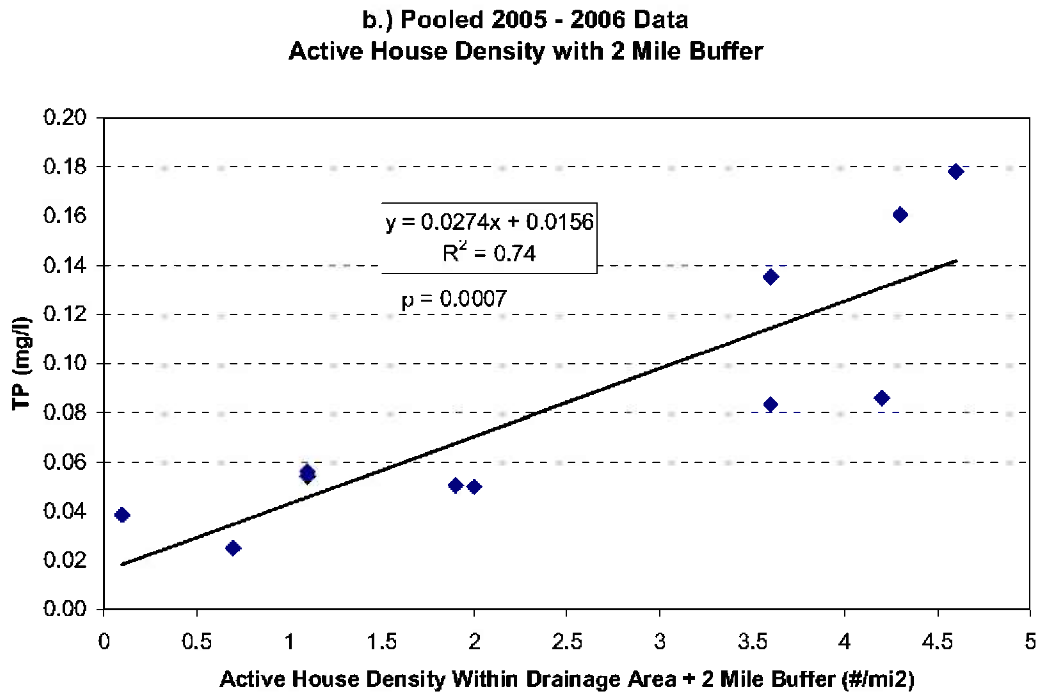
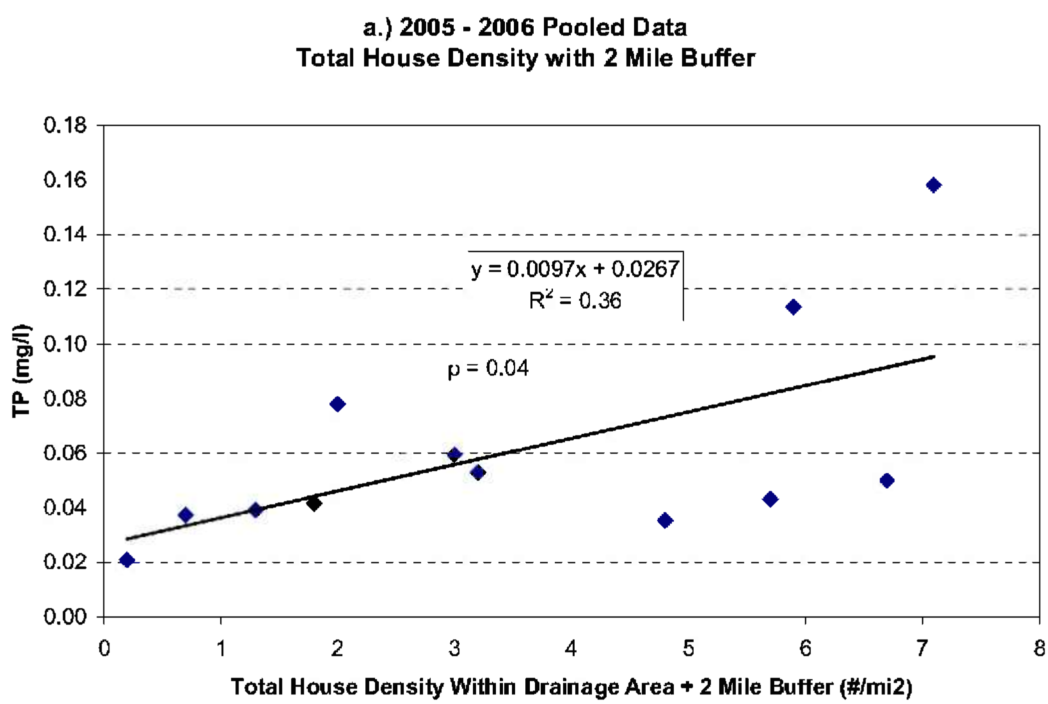


Figure 1. Highflow Regressions: Total Phosphorus Concentration vs. Poultry Presence



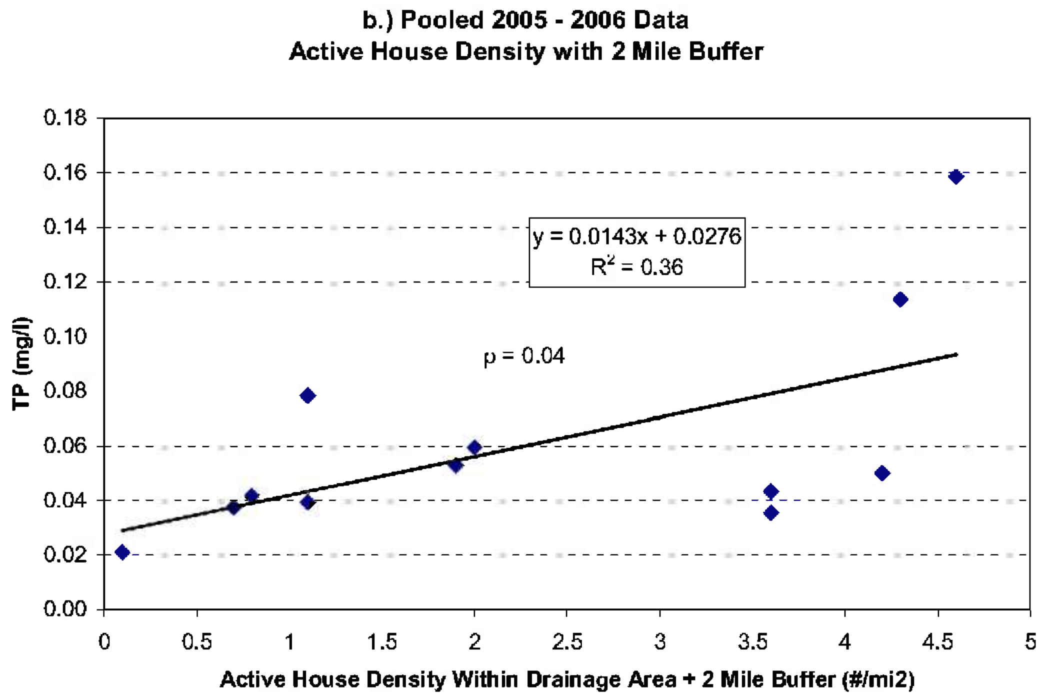


Figure 2. Baseflow Regressions: Total Phosphorus Concentration vs. Poultry Presence

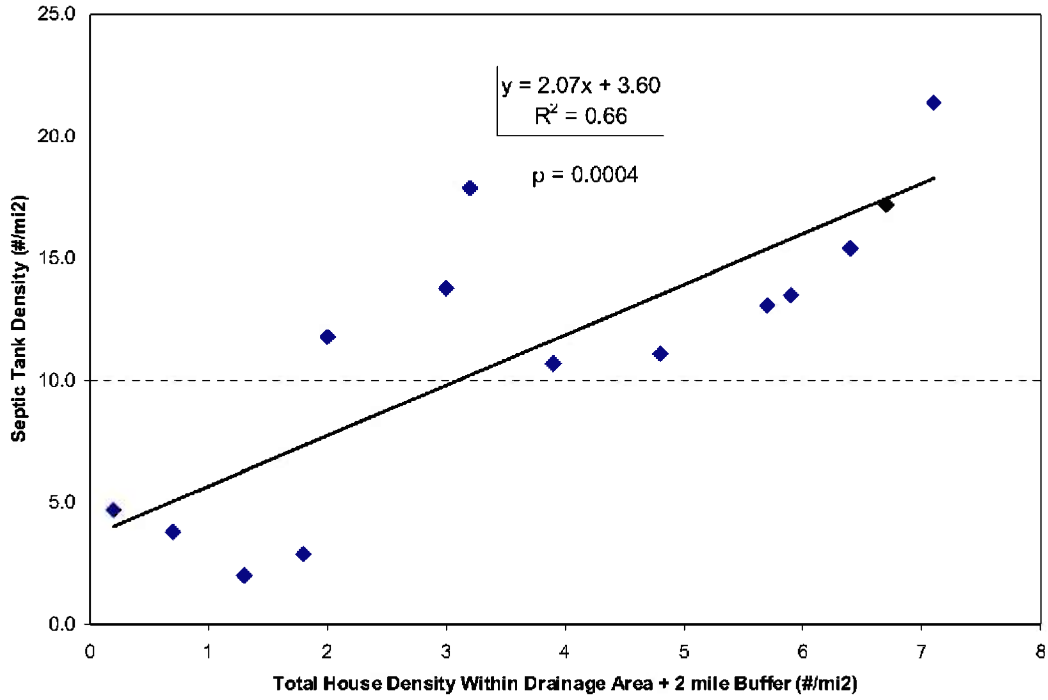


Figure 3 Cross Correlation Between Septic Tank Density and Poultry Presence

Appendix D
Hydrologic/Water Quality Modeling

Data Sources and Preparation

Spatial data for land cover, soil, elevation, soil test phosphorus (STP), poultry litter application, other nutrient applications to the landscape, and weather gage stations were used for preparation of the GLEAMS model inputs. These spatial data were processed in ArcView software in the GIS grid file format. Observed weather data were processed for GLEAMS input file generation. Observed USGS stream flow and water quality data were used for model calibration/validation processes. OWRB water quality data were also used for model calibration and validation.

Land Cover

The land cover is important information for GLEAMS modeling because land cover type influences the water budget and pollutant loading from watersheds. Most watershed models generally simulate runoff and pollutant loadings for each hydrologic response unit (HRU) which is typically defined based on land cover or a combination of land cover and soil type. Figure 1 shows the land cover for the Illinois River Basin based on the most recently available National Land Cover Dataset (NLCD) for 2001. Land use was divided into five categories: water, crop, pasture, urban and forest. The Illinois River Basin area is 4,277 km^2 and the primary land use type is pasture at about 50% (2,126 km^2) of total area followed by forest with about 40% (1,728 km^2) of total area.

Soil

Soil information is also import for GLEAMS modeling. Its characteristics influence water movement, soil erosion processes and nutrient movement. The spatial distribution of soil data was obtained from the State Soil Geographic (STATSGO) database (available from the USEPA web site (http://www.epa.gov/waterscience/htp/basins/gisdata/huc/)). The soil groups can be divided into 14 categories by STMUID and major soil group as shown in Figure 2. The STATSGO database contains numerous soil properties for each soil group that were used in parameterizing GLEAMS.

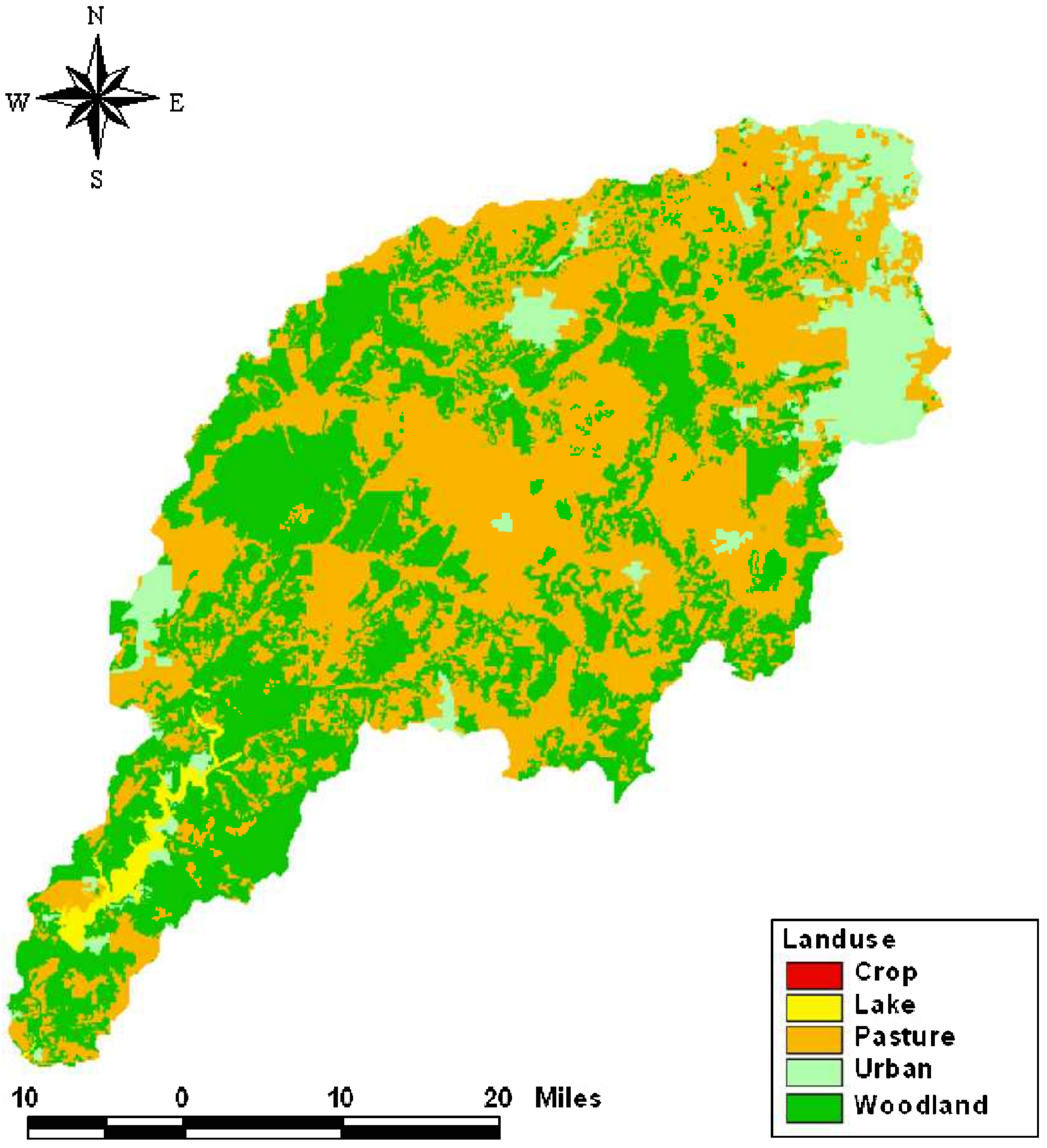


Figure 1. Land cover distribution for Illinois River Basin based on NLCD 2001 data

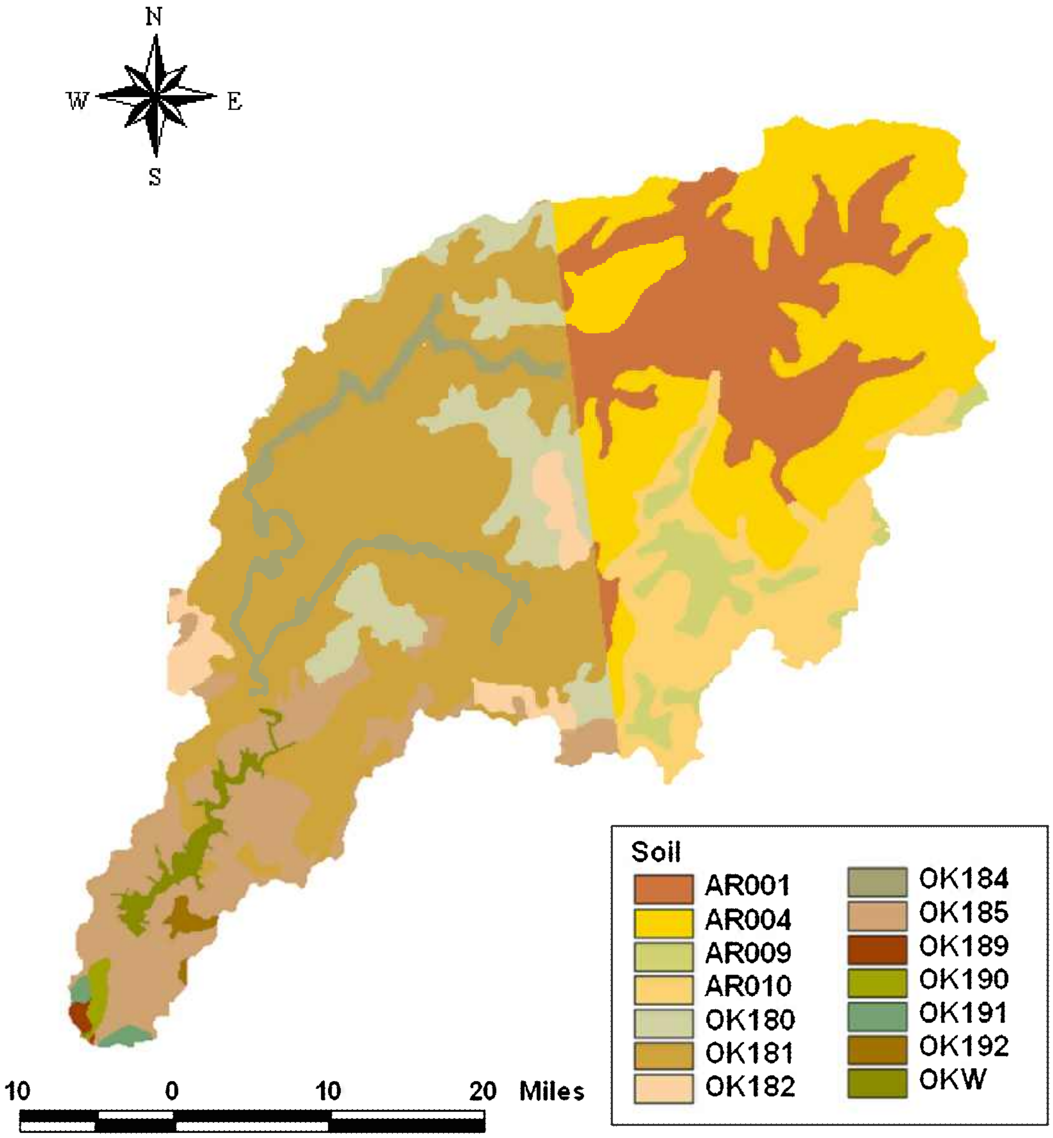


Figure 2. STATSGO soil type distribution for Illinois River Basin

Topography

The topographic characteristics determine the water movement within watersheds and can be defined by a digital elevation model (DEM). The DEM for the Illinois River Watershed was obtained from the USGS with a 30m grid cell resolution and is shown in Figure 3.

Weather Data

Observed daily precipitation and average monthly temperature were used in the GLEAMS modeling. Weather data were obtained from the National Climatic Data Center (NCDC).

Weather Stations

There are several weather stations in the Illinois River Basin. Various precipitation patterns need to be considered in GLEAMS model application. Therefore, the distribution of weather gage stations was generated as ArcView (GIS) point data using latitude and longitude information of weather stations at the NCDC website (Figure 4). Thessien polygons for the weather stations were generated using the weather station gage location data (Figure 4) to identify appropriate rainfall gages to use for locations within the Illinois River Watershed. All weather stations have not been monitored continuously and most weather stations which are being monitored for rainfall have not been monitored for temperature at the same station. Table 1 shows the selected weather stations which are operated currently.

Table 1. Weather stations used to model Baron Fork, Illinois River, and Caney Creek Basins

	Baron Fork	Illinois River	Caney Creek
Rainfall stations	035354, 348506	032444, 344672, 348677	348506
Temperature station	9450	9450	9450

Weather Data

Daily rainfall and temperature data were downloaded from the NCDC website. Average monthly temperature data were obtained using the last 30 years of daily temperature data from the stations identified in Table 1.

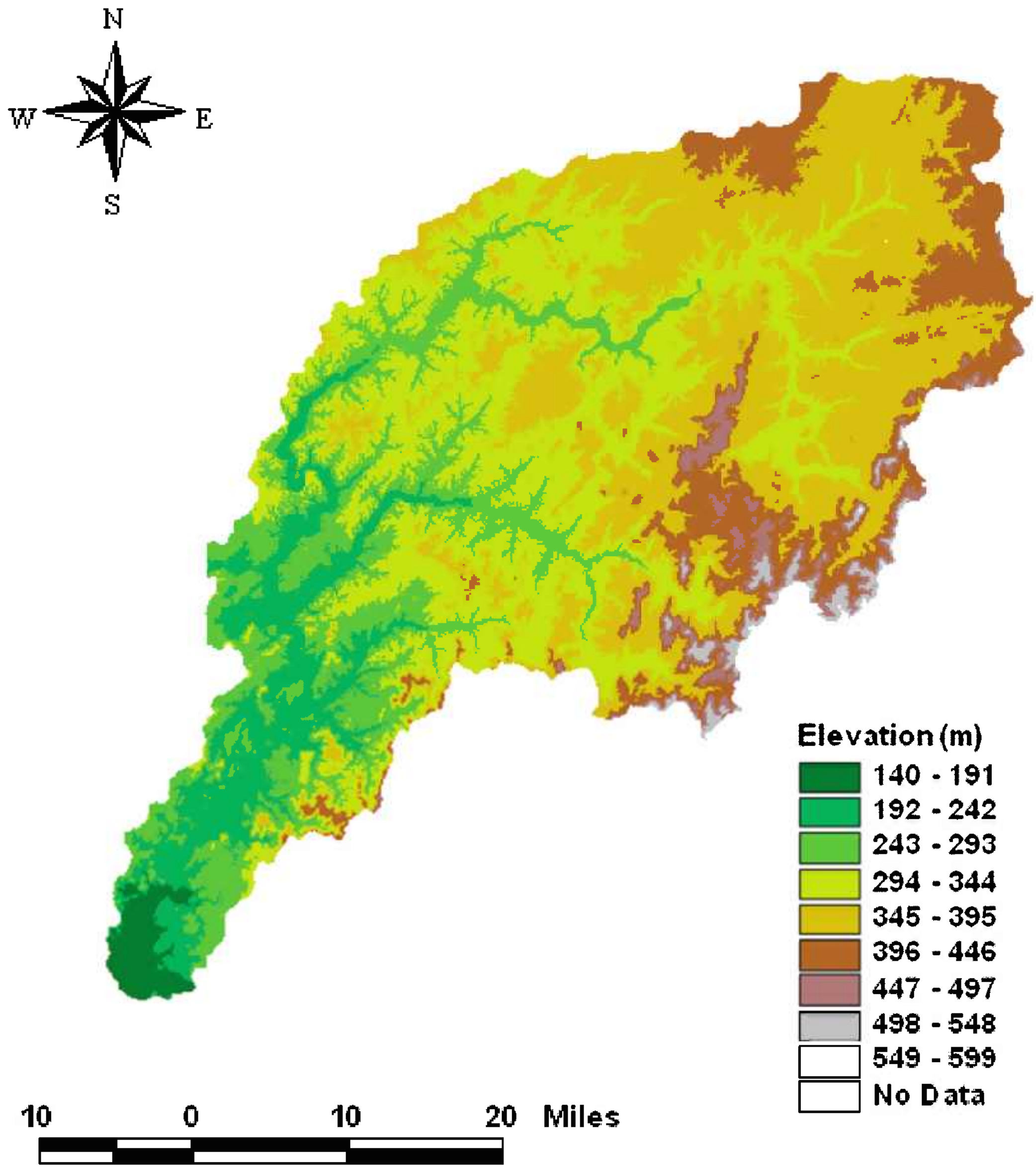


Figure 3. USGS DEM for the Illinois River Basin

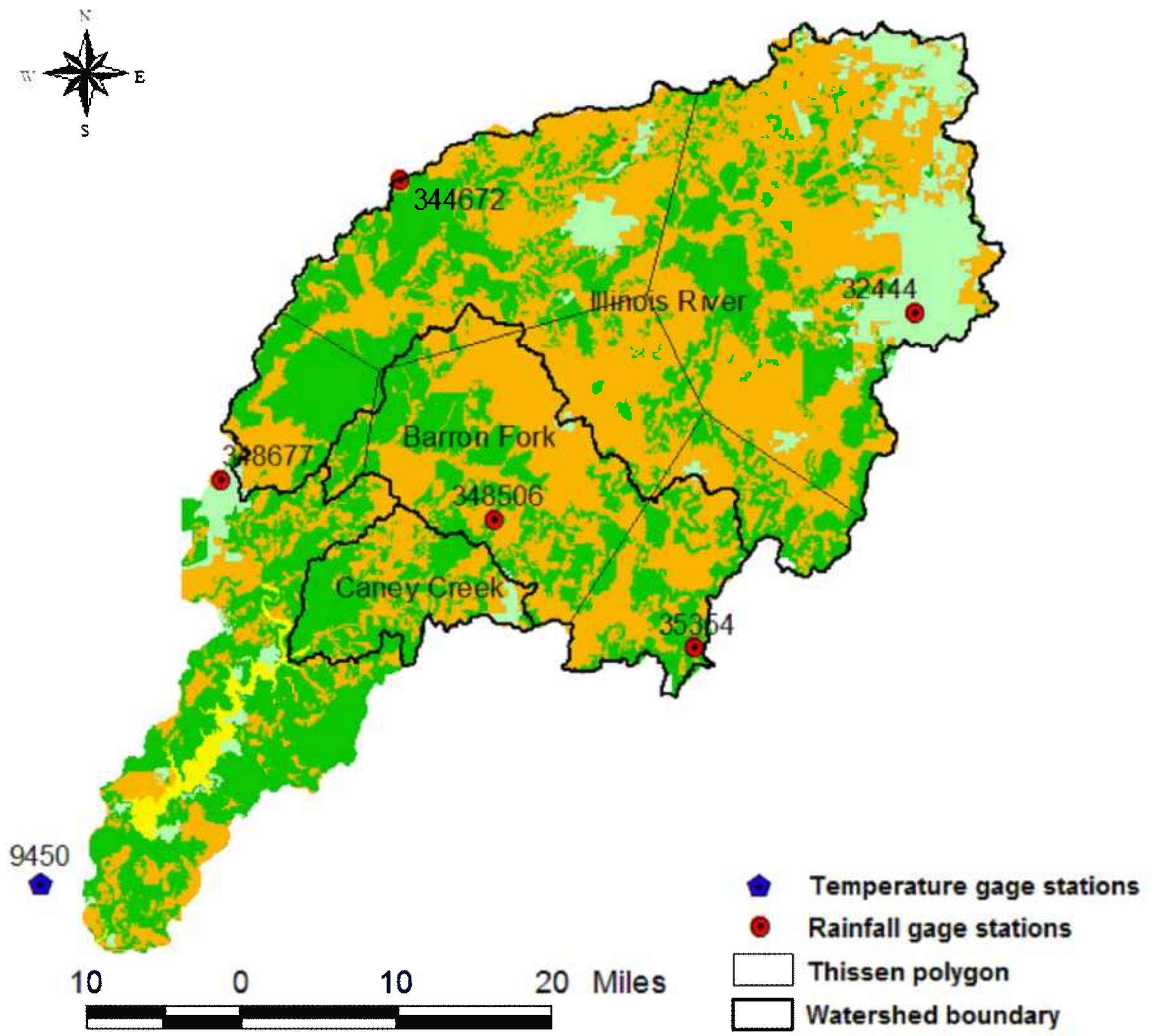


Figure 4. Rainfall gage station locations and rainfall Thiessen polygons derived from these gages

Stream flow data

Streamflow data were obtained from USGS streamflow gauging stations, and each USGS streamflow gauging station with name of the study watersheds is listed in Table 2.

Table 2. USGS gage stations for each watershed

	USGS gage station
Illinois River	USGS 07196500 Illinois River near Tahlequah, OK
Barron Fork	USGS 07197000 Barron Fork at Eldon, OK
Caney Creek	USGS 07197360 Caney Creek near Barber, OK

GLEAMS Modeling Approach

GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) is a one-dimensional mathematical model for field-scale assessment and it assumes that the area to which it is applied is homogenous for hydrological and pollutant loading characteristics. Therefore, input files were generated and the GLEAMS model was used to represent landuse, soil, management, and weather combinations for watershed scale application. For the hydrologic simulation, the combination of land use and soil type is a hydrologic response unit so GLEAMS input file for hydrologic simulation were generated based on these two combinations. For the pollutant loading simulation, the combination of land use type and pollutant loading characteristics of watershed form a homogenous loading response unit so four zones were created using poultry house density (Figure 6). GLEAMS input files for pollutant loading simulation were generated as the combination of land use type and four zones. Therefore, several hydrologic input files which have the same land use type but different soil type shared pollutant loading input files which had the same land use type (Figure 5).

Additional details about GLEAMS are provided in the GLEAMS User's Manual and in Lim and Engel (2003), Lim et al. (2006), Mitchell Adeuya et al. (2005), and Thomas et al. (2007).

Hydrologic simulation input file generation

Most hydrologic parameters for the GLEAMS model came from STATSGO information and the GLEAMS manual as follows.

DAREA is the area for each hydrologic response unit and was generated using the clipped GIS layer for the combination of land use, soil and poultry house density.

RC is the effective saturated conductivity of the soil horizon immediately below the root zone (cm/hr). This value was obtained from the saturated hydraulic conductivity information (SOL_K) of the deepest STATSGO soil layer.

CONA is the soil evaporation parameter and was obtained from the GLEAMS manual as shown in Table 3.

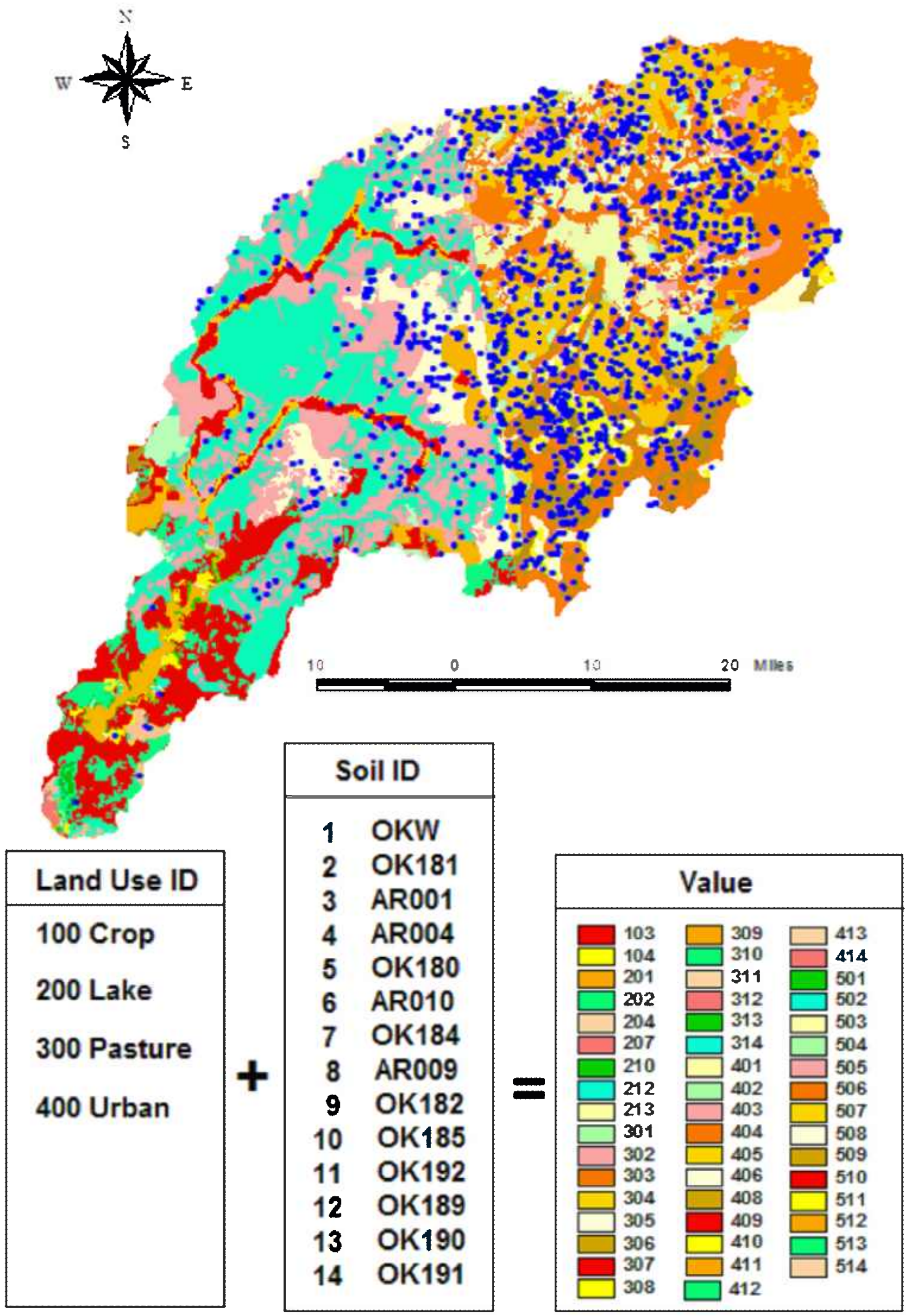


Figure 5. The combination of land use and soil

Table 3. Physical properties of soils by textural classification from GLEAMS manual Table H-3.

Texture	Field capacity (cm/cm)	Wilting Point 1500 kPa (cm/cm)	Evap. Const. (mm/d$^{0.5}$)
Coarse sand	0.11	0.03	3.3
Sand	0.16	0.03	3.3
Find sand	0.18	0.03	3.3
Very fine sand	0.27	0.03	3.3
Loamy coarse sand	0.16	0.05	3.3
Loamy sand	0.19	0.05	3.3
Loamy fine sand	0.22	0.05	3.3
Loamy very find sand	0.37	0.05	3.3
Coarse sandy loam	0.19	0.08	3.3
Sandy loam	0.22	0.08	3.5
Fine sandy loam	0.27	0.08	3.5
Very fine sandy loam	0.37	0.08	3.5
Loam	0.26	0.11	4.5
Silt loam	0.32	0.12	4.5
Silt	0.27	0.13	4.0
Sandy clay loam	0.30	0.18	4.0
Clay loam	0.35	0.22	4.0
Silty clay loam	0.36	0.20	4.0
Sandy clay	0.28	0.20	3.5
Silty clay	0.40	0.30	3.5
Clay	0.39	0.28	3.5

CN2 is the curve number for AMC II condition. This value can be obtained from an NRCS-USDA table knowing the combination of land use and hydrologic soil type. Although land use and hydrologic soil type is the same, the CN values vary by agricultural management activity for cropped land, percentage of impervious area for urban land, cover condition for forest, and grazing condition for pasture. Whereas, exact conditions for each watershed are unknown, therefore an averaged CN value for each combination of land use and hydrologic soil group types was used (Table 4) as a starting point.

Table 4. CN values for the combination of land use and hydrologic soil group.

	Hydrologic soil group			
	A	B	C	D
Crop	64	77	84	87
Pasture	49	69	79	84
Urban	77	85	89	92
Forest	44	64	76	82

CHS is the hydraulic slope of a field and is defined as the slope of the longest flow path. The longest flow path is the flow line from the most remote point of the field boundary to the outlet of the field. This length and difference in elevation from the most remote point to the outlet are the same as those used in estimating a time of concentration of a drainage area. CHS was generated using the following equation from the GLEAMS manual.

$$CHS = \frac{ELEV_{mx} - ELEV_{mn}}{LFP}$$

Where, $ELEV_{mx}$ and $ELEV_{mn}$ is maximum and minimum elevation of the drainage area, respectively, and was obtained from the DEM. LFP is the length of the longest flow path and was obtained using the USEPA Reach File 1 (RF1) which was downloaded from the USEPA web site (http://www.epa.gov/waterscience/htp/basins/gisdata/huc/).

WLW, a ratio of the watershed, or field, length to the width is a relative measure of the elongation, is used in the empirical relationship to estimate peak rate of daily runoff. As WLW increases, the peak rate of runoff decreases and a watershed length width ratio was calculated as follows using an equation from the GLEAMS manual.

$$WLW = \frac{(length\ of\ longest\ flow\ path\ in\ \ field, m)^2}{Drainage\ area(m^2)}$$

Where length of longest flow path in field was generated using RF1.

RD, an effective rooting depth, was defined in GLEAMS as that which gives the best estimate of surface runoff. These values came from depth from soil surface to the bottom of the deepest layer (SOL_Z) of the soil in STATSGO.

ELEV and LAT is mean sea level elevation and location information of weather gage station which is used to estimate potential evapotranspiration by the Penman-Monteith method and was obtained from the NCDC weather station web site.

NSOHZ, number of soil horizons in the root zone, was generated from the STATSGO data.

BOTHOR, depth of bottom of each soil layer, is needed to define the profile physical dimensions. The number of horizons and their thickness enable the model to set the computational layers within the horizons and this information was obtained from SOL_Z of the last soil layer of STATSGO.

POR, soil porosity for each soil horizon, represents the maximum amount of water that a unit volume of soil can hold without any drainage. These values were calculated using bulk density using the following equation from the GLEAMS manual.

$$POR = 1 - \frac{BD}{2.65}$$

Where BD is bulk density obtained from bulk density information (SOL_BD) in STATSGO.

FC, the agronomic definition of field capacity, is used for the volumetric water content after 24 hours of drainage. This value was obtained using each soil's texture (obtained from STATSGO) and data from the GLEAMS manual as shown in Table 3.

BR15, wilting point, is defined as the volumetric water content at 1,5000 kPa matric potential. The volume of water at wilting is needed since that water contains pesticides and nutrients that react with each chemical pulse and this value is obtained using texture (obtained for each soil from STATSGO) and the GLEAMS manual as shown in Table 3.

SATK, saturated conductivity in each soil horizon, was generated from SOL_K of each soil layer using STATSGO data.

CLAY and SILT, percent of clay and silt mass in each soil horizon, respectively, are important data in the GLEAMS model because the relative amounts determine the textural classification which are used in estimating porosity and field capacity. These were obtained from STATSGO data.

Table 5. Original soil properties and calibrated soil properties for four soils

	AR001				AR009			
	Original	Illinois River	Barron Fork	Caney Creek	Original	Illinois River	Barron Fork	Caney Creek
RC	0.004	0.003	0.005	0.006	0.607	0.509	0.825	0.894
RD	61.71	34.29	32.96	83.93	28.54	15.86	15.24	38.82
BOTHOR(1)	10.03	5.57	5.36	13.64	3.86	2.14	2.06	5.25
BOTHOR(2)	36.26	20.15	19.36	49.32	7.71	4.28	4.12	10.49
BOTHOR(3)	61.71	34.29	32.96	83.93	19.28	10.71	10.30	26.22
BOTHOR(4)					27.00	15.00	14.42	36.72
BOTHOR(5)					28.54	15.86	15.24	38.82
FC(1)	0.509	0.444	0.482	0.330	0.453	0.395	0.429	0.293
FC(2)	0.479	0.418	0.453	0.310	0.453	0.395	0.429	0.293
FC(3)	0.509	0.444	0.482	0.330	0.453	0.395	0.429	0.293
FC(4)					0.453	0.395	0.429	0.293
FC(5)					0.057	0.050	0.054	0.037
BR(1)	0.320	0.338	0.350	0.256	0.270	0.285	0.296	0.216
BR(2)	0.360	0.380	0.394	0.288	0.260	0.275	0.285	0.208
BR(3)	0.390	0.412	0.427	0.312	0.300	0.317	0.329	0.240
BR(4)					0.300	0.317	0.329	0.240
BR(5)					0.010	0.011	0.011	0.008
SATK(1)	0.120	0.105	0.119	0.101	0.080	0.070	0.079	0.067
SATK(2)	0.200	0.174	0.199	0.168	0.110	0.096	0.109	0.092
SATK(3)	0.280	0.244	0.278	0.235	0.180	0.157	0.179	0.151
SATK(4)					0.180	0.157	0.179	0.151
SATK(5)					0.009	0.008	0.009	0.007
OM(1)	0.070	0.059	0.095	0.103	2.551	2.137	3.465	3.756

OM(2)	0.013	0.011	0.018	0.019	0.607	0.509	0.825	0.894
OM(3)	0.004	0.003	0.005	0.006	0.607	0.509	0.825	0.894
OM(4)					0.425	0.356	0.577	0.626
OM(5)					12.148	10.178	16.502	17.888

	AR010				OK182			
	Original	Illinois River	Barron Fork	Caney Creek	Original	Illinois River	Barron Fork	Caney Creek
RC	0.010	0.008	0.014		0.004	0.003	0.005	0.006
RD	47.83	26.57	25.54		37.03	20.57	19.78	50.36
BOTHOR(1)	1.54	0.86	0.82		9.26	5.14	4.95	12.59
BOTHOR(2)	3.86	2.14	2.06		12.34	6.86	6.59	16.78
BOTHOR(3)	6.17	3.43	3.30		35.48	19.71	18.95	48.26
BOTHOR(4)	30.08	16.71	16.06		37.03	20.57	19.78	50.36
BOTHOR(5)	47.83	26.57	25.54					
FC(1)	0.479	0.418	0.453		0.453	0.395	0.429	0.293
FC(2)	0.479	0.418	0.453		0.426	0.372	0.403	0.296
FC(3)	0.472	0.412	0.447		0.442	0.386	0.418	0.336
FC(4)	0.509	0.444	0.482		0.057	0.050	0.054	0.037
FC(5)	0.498	0.435	0.471					
BR(1)	0.260	0.275	0.285		0.360	0.380	0.394	0.288
BR(2)	0.260	0.275	0.285		0.360	0.380	0.394	0.288
BR(3)	0.360	0.380	0.394		0.400	0.423	0.438	0.320
BR(4)	0.320	0.338	0.350		0.040	0.042	0.011	0.032
BR(5)	0.320	0.338	0.350					
SATK(1)	0.110	0.096	0.109		0.200	0.174	0.199	0.168
SATK(2)	0.110	0.096	0.109		0.200	0.174	0.199	0.168
SATK(3)	0.200	0.174	0.199		0.300	0.262	0.298	0.252
SATK(4)	0.120	0.105	0.119		0.030	0.026	0.009	0.025
SATK(5)	0.120	0.105	0.119					
OM(1)	0.547	0.458	0.743		0.152	0.127	0.206	0.224
OM(2)	0.516	0.432	0.701		0.009	0.008	0.012	0.013
OM(3)	0.011	0.009	0.015		0.004	0.003	0.005	0.006
OM(4)	0.005	0.004	0.007		6.074	5.089	8.215	8.944
OM(5)	0.004	0.003	0.005					

Phosphorus simulation input file generation

For the phosphorus simulation, parameters related to phosphorus simulation were selected and determined from various data sources. The parameters for each Zone were estimated based on the observed data from the watershed and number of poultry houses.

Total poultry houses in study area: 3662

Total poultry houses in Zone 1: 759

Total poultry houses in Zone 2: 662

Total poultry houses in Zone 3: 2200

Total poultry houses in Zone 4: 41

CLAB(), labile phosphorus concentration in the soil horizon, was estimated for pasture land uses based on observed data. The CLAB() values for zones 1 and 2 ranged from 80 to 300, and for zone 3 ranged from 300 to 700 (Table 6).

Table 6. Observed CLAB for each county

County name	CLAB	County name	CLAB
Benton	655	Delaware	204
Washington	581	Cherokee	110
Adair	229	Sequoyah	82

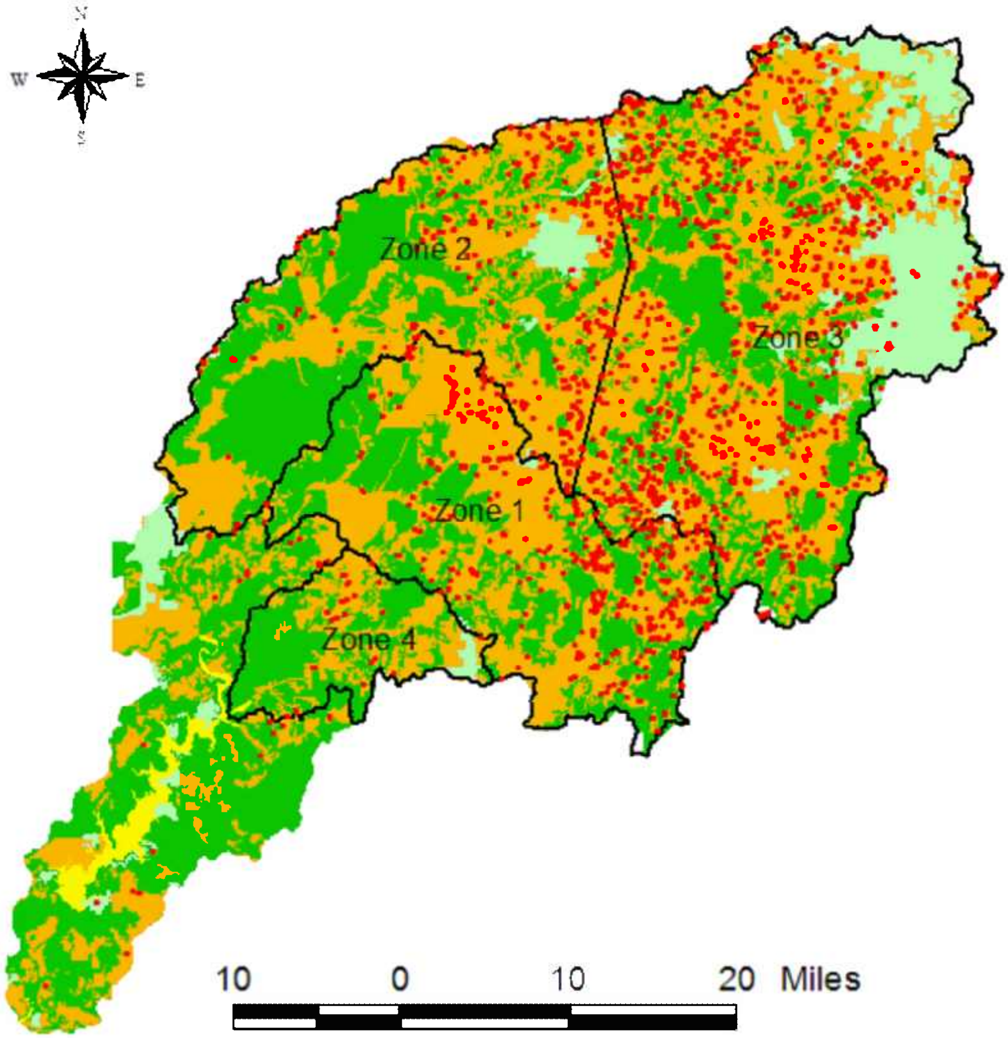


Figure 6. Four zones divided by number of poultry houses for nutrient simulation.

RATE, rate of application, represents animal waste application as solid, slurry, or liquid and is expressed as kg/ha dry matter. This value for pasture land use type is generated using observed poultry litter data as follows.

Total applied litter for the study area was 223,000 tons/yr on a dry weight basis.

Total applied litter for Zone 1:

$$=223{,}000 tons/yr \times \frac{759\ poultry\ houses}{3536\ polutry\ houses\ for\ toal} \times \frac{1}{47{,}720 ha} = 1.00 tons/ha$$

Total applied litter for Zone 2:

$$=223{,}000 tons/yr \times \frac{662\ poultry\ houses}{3536\ polutry\ houses\ for\ toal} \times \frac{1}{49{,}457 ha} = 0.84 tons/ha$$

Total applied litter for Zone 3:

$$=223{,}000 tons/yr \times \frac{2200\ poultry\ houses}{3536\ polutry\ houses\ for\ toal} \times \frac{1}{85{,}658 ha} = 1.62 tons/ha$$

Total applied litter for Zone 4:

$$=223{,}000 tons/yr \times \frac{41\ poultry\ houses}{3536\ polutry\ houses\ for\ toal} \times \frac{1}{10{,}915 ha} = 0.24 tons/ha$$

APHOS, total phosphorus content as a % in animal waste, was estimated by observed data. Total applied litter and phosphorus within the study area were 223,000 tons/yr on a dry basis and 4,642 P tons/yr (Mass Balance Analysis), respectively.

$$APHOS = \frac{4642\ P\ tons/yr}{223000\ litter\ tons/yr} = 0.0208 = 2.08\%$$

APORGP, organic phosphorus content in animal waste, was generated using APHOS and the ratio of organic and total phosphorus as described in the GLEAMS manual as follows.

	Range (Organic P/TP)	Average
Solid	0.95-1.00	0.98

Fertilizer in GLEAMS was set as animal waste (MFERT=1) for poultry waste and applied April 1 (NF=91 as Julian day).

Additional nutrient inputs were applied based on the nutrient inputs into the IRW identified by the Mass Balance Analysis. These include P from the following sources in the following amounts: swine 177 tons, dairy cattle 319 tons, beef cattle 105 tons and commercial fertilizer 455 tons.

Point source consideration

To estimate the total loads of P in streams and into Lake Tenkiller, point source pollution needs to be considered. However, GLEAMS does not consider the point source pollution, so point source pollution was added to nonpoint source pollution simulated by GLEAMS. Point source pollution in the study area is shown in Table 6.

Table 6. WWTP Total P Discharge to Streams and Rivers within the IRW

	Early 90s-2002	**2003-present**
WWTP	**P Load (lb/yr)**	**P Load (lb/yr)**
Springdale	95,128	25,112
Siloam Springs	22,046	29,638
Fayetteville - Noland	9,921	5,147
Rogers	47,619	16,206
Lincoln	2,646	2,336
Prairie Grove	2,646	3,285
Tahlequah	10,362	2,738
Stillwell	0	2,519
Westville	6,393	840
Gentry	3,748	2,336
Watts	1,102	0
Midwestern nursery	1,323	0
Cherokee Nation	1,168	0
Total	**204,101**	**90,155**

Calibration

The GLEAMS model was linked with the Shuffled Complex Evolution Algorithm (SCE-UA) because it is widely used to optimize hydrologic models. Optimization approaches are typically faster and less subjective than manual methods of model calibration. In addition, it is likely that model results are better than that which could be manually obtained. Calibration and validation processes were performed based on approximately 10 year simulation periods, considering available data. For the hydrologic simulation, both calibration (1996-2005) and validation (1986-1995) were performed. For the phosphorus simulation, calibration was performed with 1998 through 2002 data, and validation was performed using 2003 through 2006 data. Beginning in 1998, runoff events were targeted for P sampling and thus P data from 1998 through 2006 were used in the P calibration and validation.

Calibration parameters were selected by referring to the GLEAMS manual. The GLEAMS manual explains which parameters are most sensitive. Most parameters were generated based on observed data and documented databases so the optimization range was set as ±50% of estimated values to avoid searching extreme values and to insure that calibrated parameters were within reasonable ranges. For optimizing the model parameters for soil series, multiple factors were obtained as optimized parameters to maintain the relationship among the soil series. Therefore, calibrated values for soil series were obtained by multiplying the optimized factors and default values related to soil series.

P Routing Model

The GLEAMS model simulates nutrient movement to the bottom of the root zone and to the edge of HRUs. Therefore, an additional model to route nutrients through streams/rivers and to Lake Tenkiller was necessary. An empirical model was selected that used observed data to create a relationship between stream or river flow and P accumulation in the streams and rivers. This is similar to the approach used in various modeling tools including LOADEST (Runkel et al., 2004). A P routing model was created for each gauging location used in the modeling effort (Tahlequah, Baron Fork near Eldon, and Caney Creek). The equations were of the form:

$$P\ Load = a + b * Q * P\ Accumulation + c * Q^2 * P\ Accumulation$$

Where P Load is a daily P load in lbs

a, b, and c are coefficients obtained during equation development

Q is average daily flow rate at USGS gauge

P Accumulation is computed P accumulated in the stream or river

GLEAMS Model Calibration and Validation

P Routing Model

The P routing model coefficients were determined for the three USGS locations used in the modeling effort (Tahlequah, Baron Fork near Eldon, and Caney Creek). An iterative process was used to model P with GLEAMS and use USGS flow data to fit the coefficients for observed P loads between 1998 through 2002. The routing model coefficients were optimized using an automated Shuffled Complex Evolution approach.

The optimized coefficients for each location are shown in Table 7.

Table 7. Coefficients for P load routing models

Location	a	b	c	Initial P Accumulation (lbs)
Tahlequah	0.101	$4.88 * 10^{-7}$	$1.26 * 10^{-10}$	500,000
Baron Fork	0.101	$5.46 * 10^{-13}$	$1.00 * 10^{-9}$	100,003
Caney Creek	0.101	$8.93 * 10^{-12}$	$5.10 * 10^{-8}$	10,000

Hydrologic Calibration

The performance of the GLEAMS hydrologic simulation following automatic calibration shows GLEAMS is able to estimate monthly runoff values well. Monthly calibration for Baron Fork River and Illinois River produced Nash-Sutcliffe efficiencies (NS) of 0.64 and 0.63, respectively (Table 8). Time-series and 1:1 scatter plots of simulated and observed stream flow illustrated the fit is reasonable at the two gage sites. For the yearly NS, the highest value was obtained for 2005 with NS values of 0.94 for Baron Fork River and 0.86 for the Illinois River. The worst NS was obtained for 2003 which was a dry year.

Figures 7-12 show predicted and observed flows during the calibration period.

Table 8. Calibrated model performance for runoff

	Baron Fork		Illinois River		Caney Creek	
	NS	R^2	NS	R^2	NS	R^2
1996	0.79	0.82	0.45	0.80	Data is not available	
1997	0.45	0.48	0.22	0.31	Data is not available	
1998	0.53	0.54	0.45	0.49	0.79	0.84
1999	0.72	0.76	0.67	0.84	0.62	0.74
2000	0.79	0.83	0.79	0.85	0.64	0.65
2001	0.73	0.75	0.73	0.76	0.78	0.83
2002	0.17	0.33	0.45	0.61	0.64	0.80
2003	-20.22	0.00	-0.06	0.19	-1.89	0.03
2004	0.68	0.94	0.39	0.51	-0.49	0.47
2005	0.94	0.98	0.81	0.96	0.97	0.99
Average	0.64	0.65	0.63	0.68	0.51	0.60

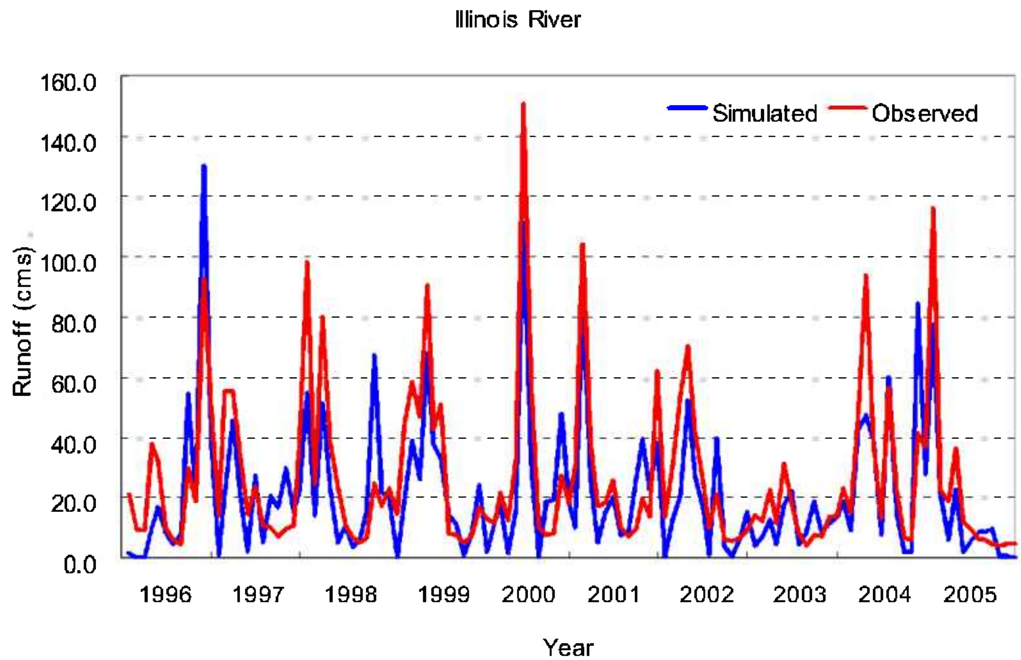


Figure 7. Hydrologic calibration for Illinois River Basin at Tahlequah.

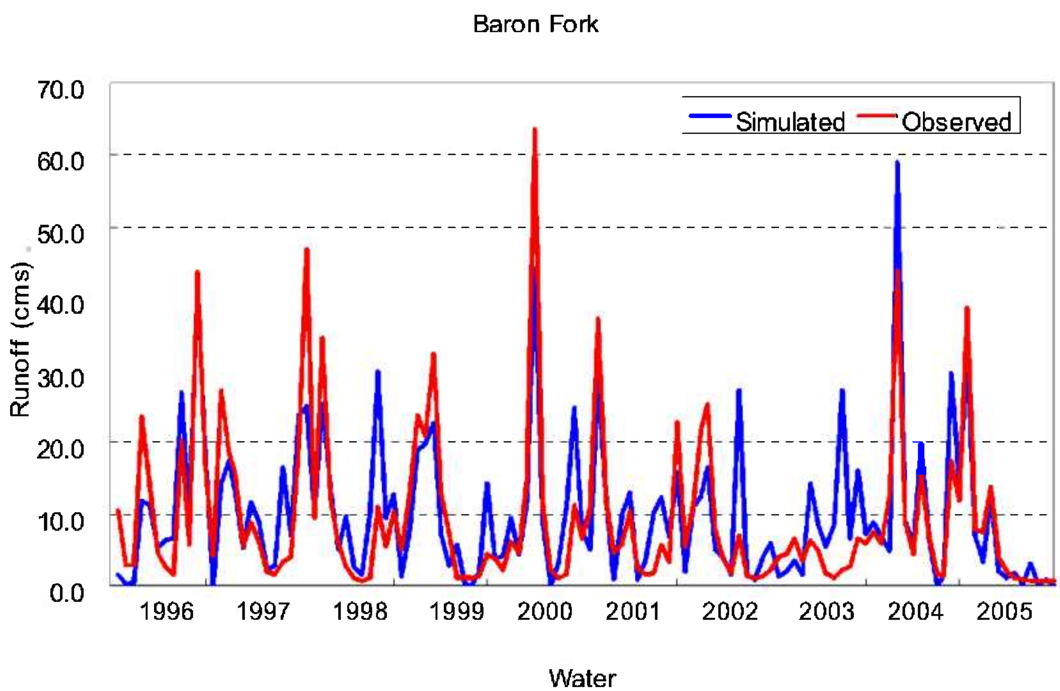


Figure 8. Hydrologic calibration for Baron Fork Basin.

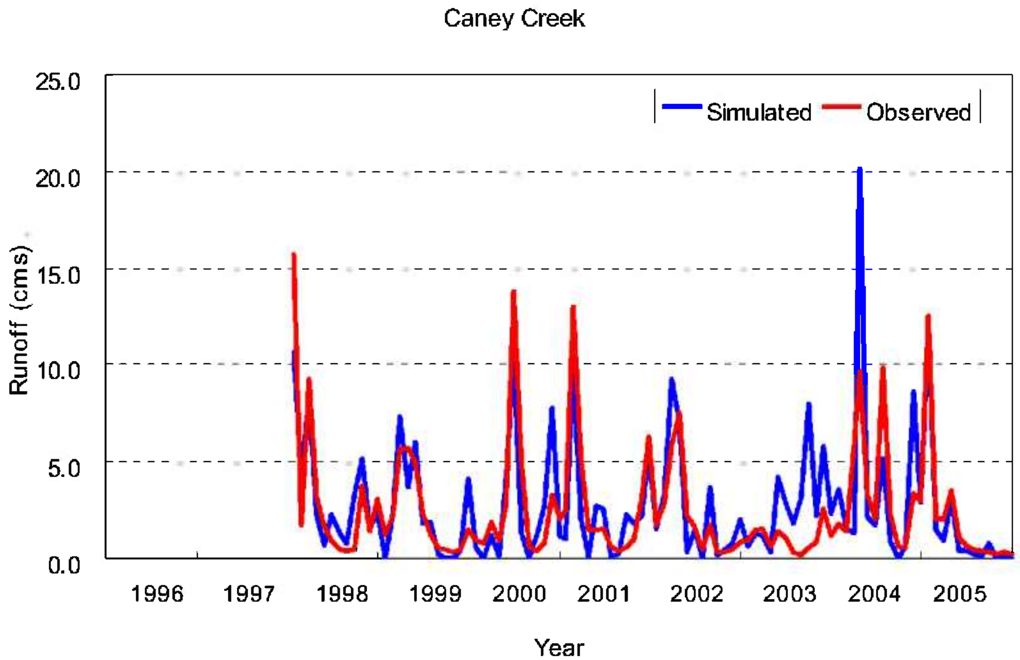


Figure 9. Hydrologic calibration for Caney Creek Basin.

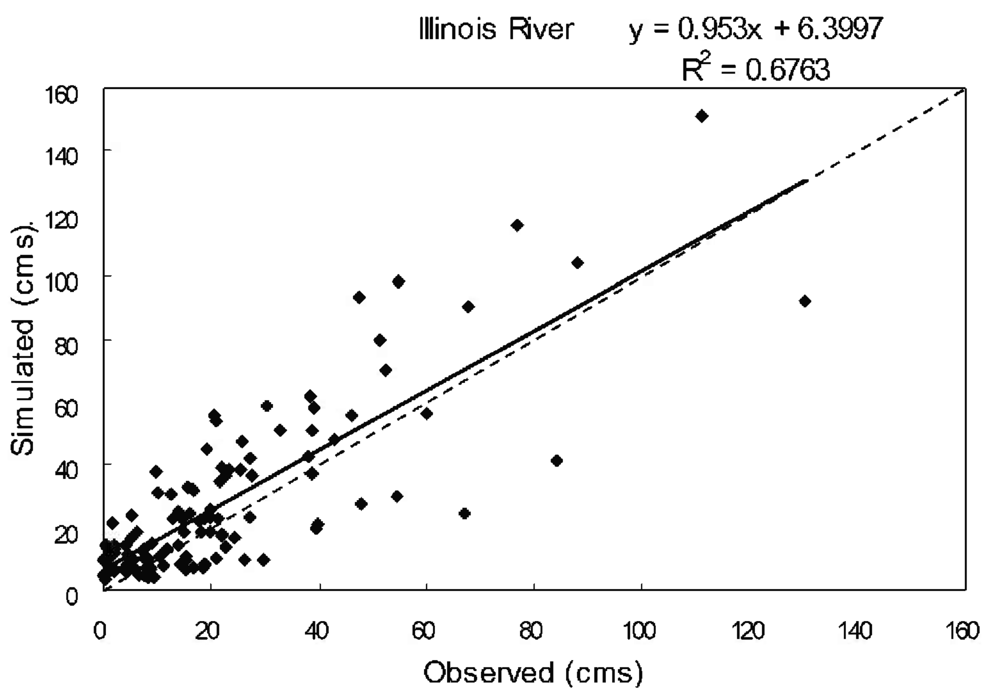


Figure 10. Scatter plot of hydrologic calibration for Illinois River Basin at Tahlequah

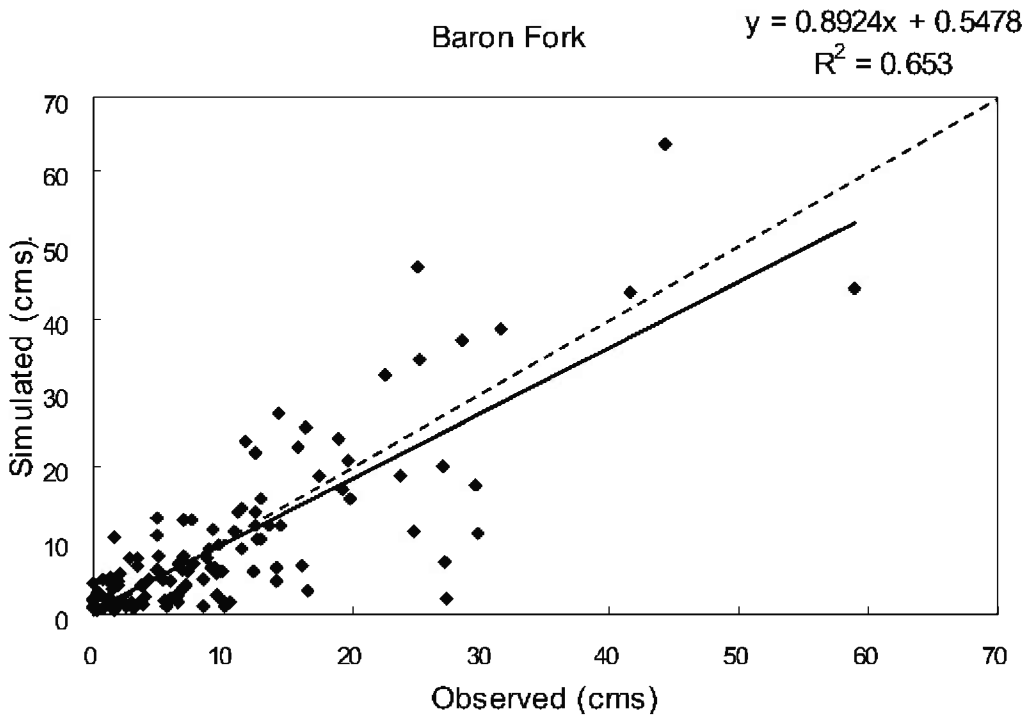


Figure 11. Scatter plot of hydrologic calibration for Baron Fork Basin

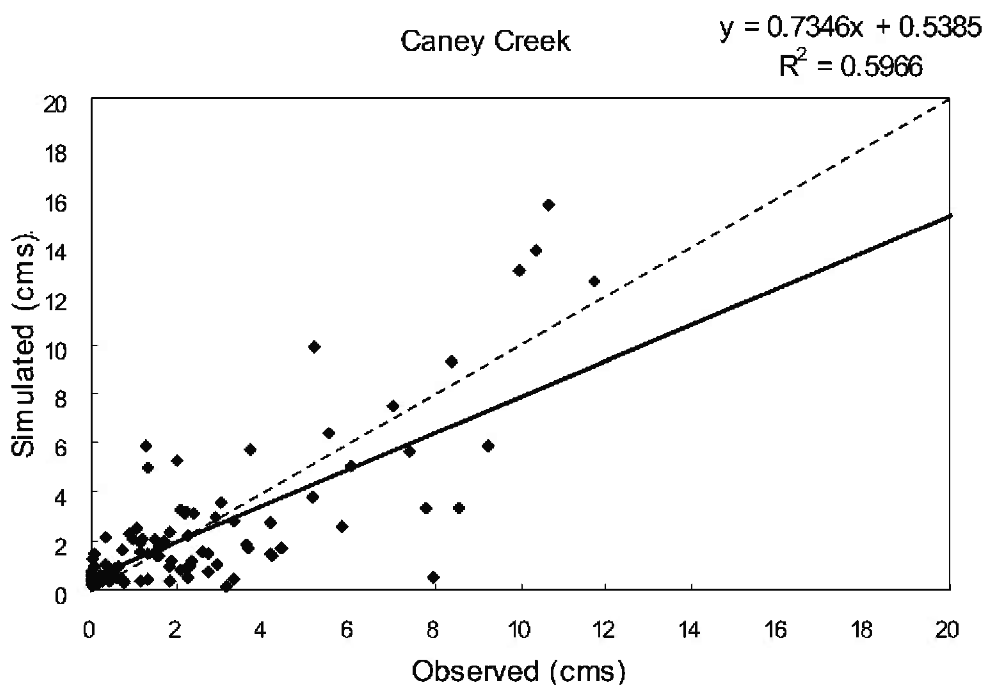


Figure 12. Scatter plot of hydrologic calibration for Baron Fork Basin

Hydrologic Validation

Validation is a subsequent testing of a pre-calibrated model with additional field data, usually under different external conditions, to further examine the model's ability to predict future conditions. Validation improves the reliability of the model and reduces the uncertainty in its predictions. Hydrologic validation was performed using 1986-1995 data for the two watersheds. The NS values for Baron Fork and Illinois River were 0.73 and 0.59, respectively, and illustrated that the calibrated GLEAMS model could predict for a range of conditions (Table 9). Based on these results, the calibrated model can be used to model scenarios of interest with confidence. The best and worst NS values for the Baron Fork were for 1990 and 1994 with 0.87 and 0.26, respectively, and those for the Illinois River were for 1990 and 1993 with 0.83 and -0.09, respectively.

Table 9. Results for hydrologic validation

	Baron Fork		Illinois River		Caney Creek	
	NS	R^2	NS	R^2	NS	R^2
1986	0.69	0.75	0.24	0.49	Data is not available	
1987	0.76	0.79	0.62	0.69		
1988	0.41	0.49	0.46	0.61		
1989	0.82	0.88	0.77	0.82		
1990	0.84	0.85	0.83	0.86		
1991	0.69	0.69	0.59	0.70		
1992	0.87	0.87	0.78	0.84		
1993	0.35	0.56	-0.09	0.65		
1994	0.26	0.51	0.47	0.59		
1995	0.76	0.80	0.50	0.82		
Average	0.73	0.73	0.59	0.67		

Note: Yearly NS is that NS value calculated for each year using monthly results so 12 monthly data values were used to calculate yearly NS.

Figures 11-14 show the model performance relative to observed flow data during validation.

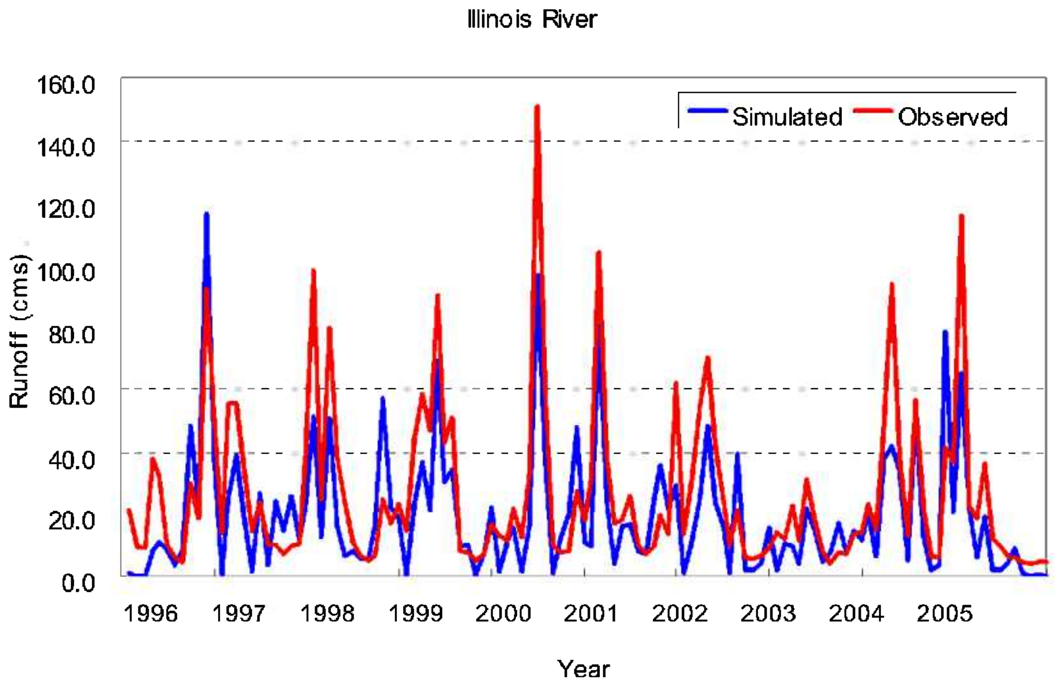


Figure 11. Hydrologic validation for Illinois River Basin at Tahlequah

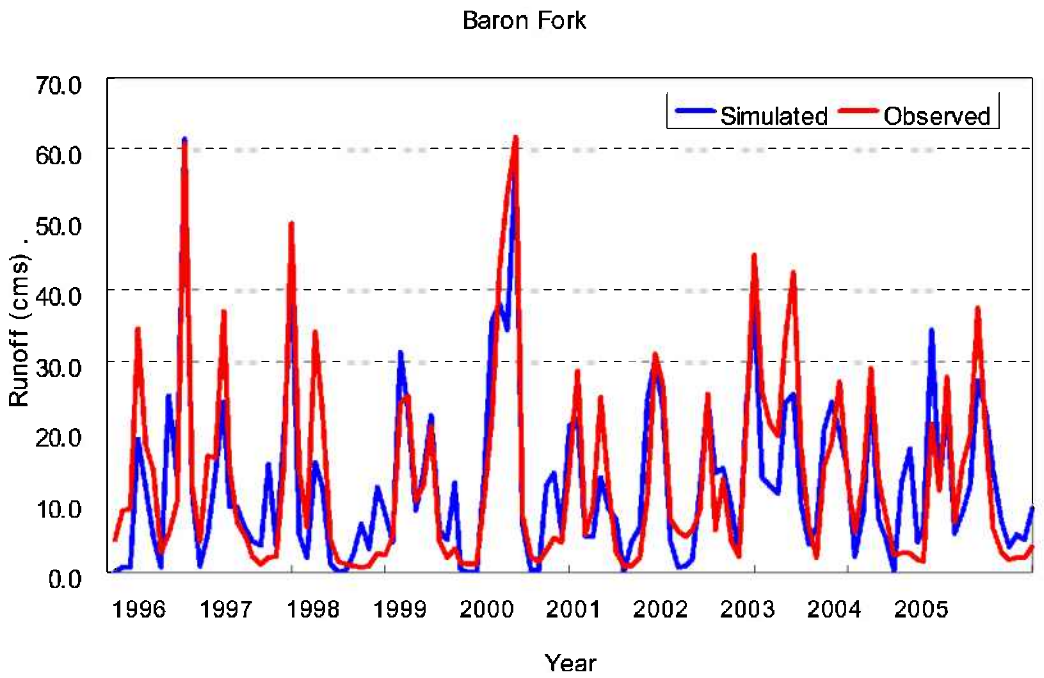


Figure 12. Hydrologic validation for Baron Fork River Basin

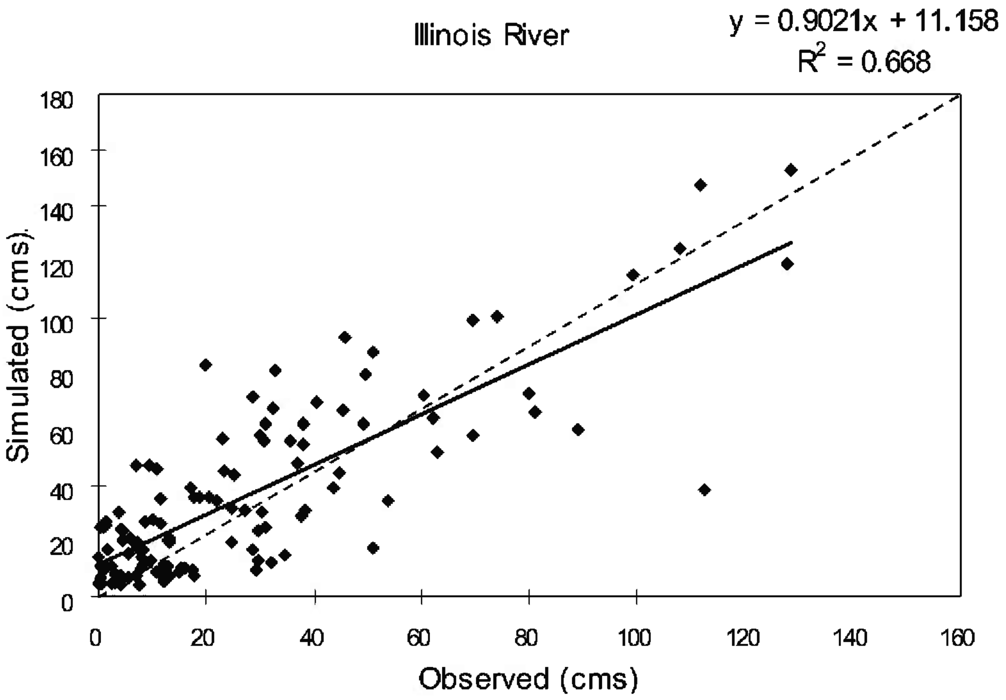


Figure 13. Scatter plot of hydrologic calibration for Illinois River Basin

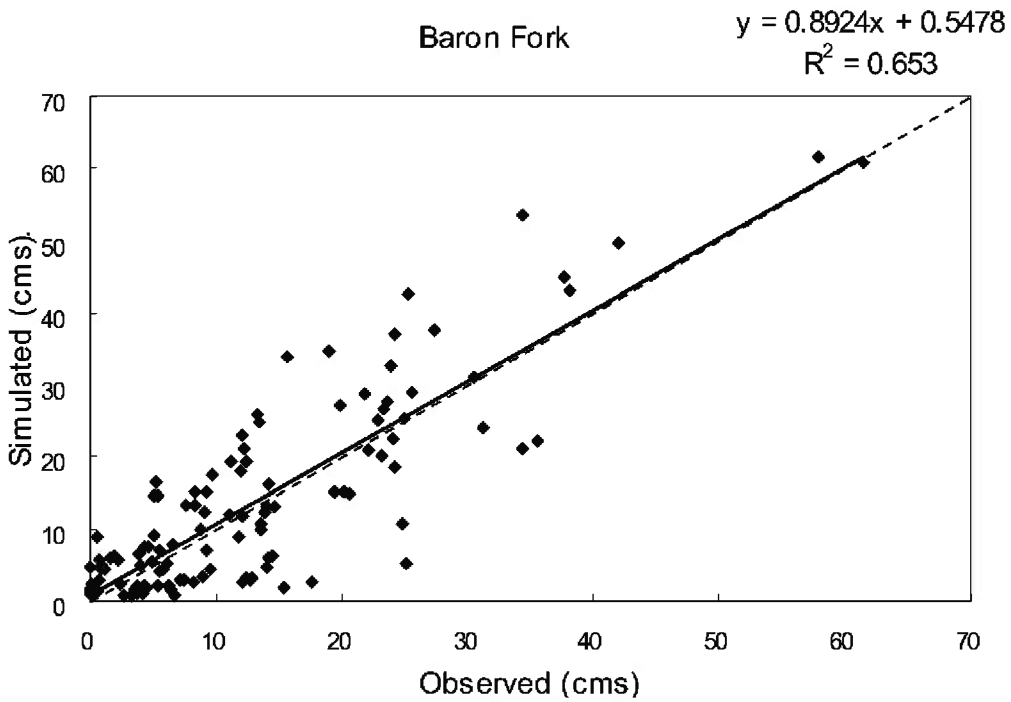


Figure 14. Scatter plot of hydrologic calibration for Baron Fork River Basin

Phosphorus Loading Calibration and Validation

For the phosphorus simulation, calibration was performed with 1998 through 2002 data, and validation was performed using 2003 through 2006 data. Beginning in 1998, runoff events were targeted for P sampling, and thus P data from 1998 through 2006 were used in the P calibration and validation. USGS and OWRB samples analyzed for total P content were used along with USGS flow data to compute observed P loads at the Tahlequah, Baron Fork near Eldon, and Caney Creek gauging stations between 1997 and 2006. The LOADEST (load estimator) software (Runkel et al., 2004) was used along with these data in calculating P loads. Tortorelli and Pickup (2006) and Pickup et al. (2003) used this approach in computing P loads for the IRW. The approach used by Tortorelli and Pickup (2006) and Pickup et al. (2003) was used in calculating P loads. The R^2 for LOADEST calculated P and observed P is shown in Table 10. The fit between calculated P and observed P is a very good fit. LOADEST can be used to calculate P loads within the IRW.

Table 10. R^2 for LOADEST Calculated P and Observed P

	R^2		
Year	**Tahlequah**	**Baron Fork**	**Caney Creek**
1998	0.95	0.89	0.87
1999	0.95	0.96	0.87
2000	0.96	0.94	0.95
2001	0.94	0.93	0.97
2002	0.92	0.93	0.98
2003	0.90	0.92	0.98
2004	0.94	0.97	0.98
2005	0.95	0.98	0.99
2006	0.95	0.98	0.99

The IRW P loads calculated with LOADEST are shown in Table 11 and show substantial variation annually due to differences in rainfall and flow into Tenkiller.

Table 11. Observed P Loads Based on USGS and OWRB P Data and USGS Flow Data

	Total P (lb/yr)			
Year	Tahlequah	Baron Fork	Caney Creek	Total
1997	211,467	25,500	4,140	241,107
1998	422,906	39,887	9,024	471,817
1999	392,336	49,755	8,349	450,440
2000	771,454	298,307	55,787	1,125,548
2001	456,947	98,931	36,616	592,494
2002	301,474	52,666	16,574	370,714
2003	94,684	10,107	3,485	108,276
2004	631,798	459,054	57,086	1,147,938
2005	258,021	68,639	14,004	340,664
2006	128,415	58,300	10,574	197,289

The daily calibration R^2 results for 1998 through 2002 are shown in Figures 15-17. The daily Nash-Sutcliffe Coefficients are: Tahlequah 0.95, Baron Fork 0.98, and Caney Creek 0.94 (Table 12).

The daily validation R^2 results for 2003 through 2006 are shown in Figures 18-20.

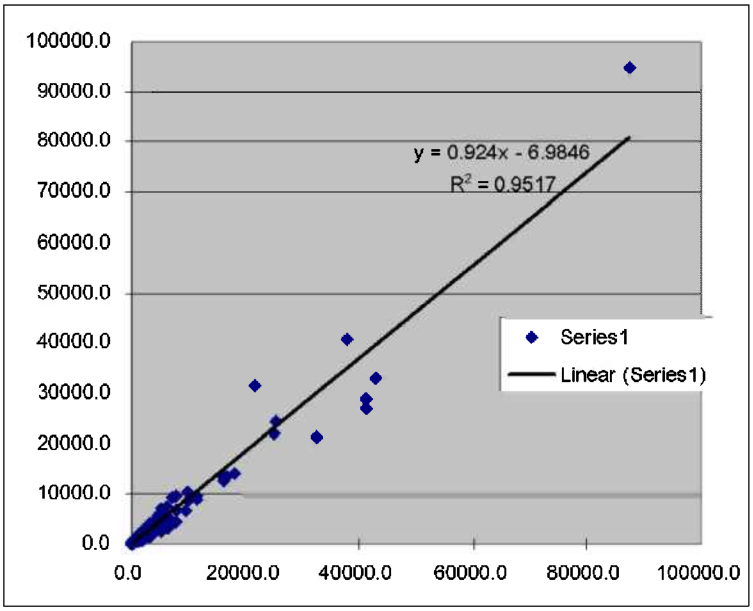


Figure 15. Calibration for Daily P Load at Tahlequah

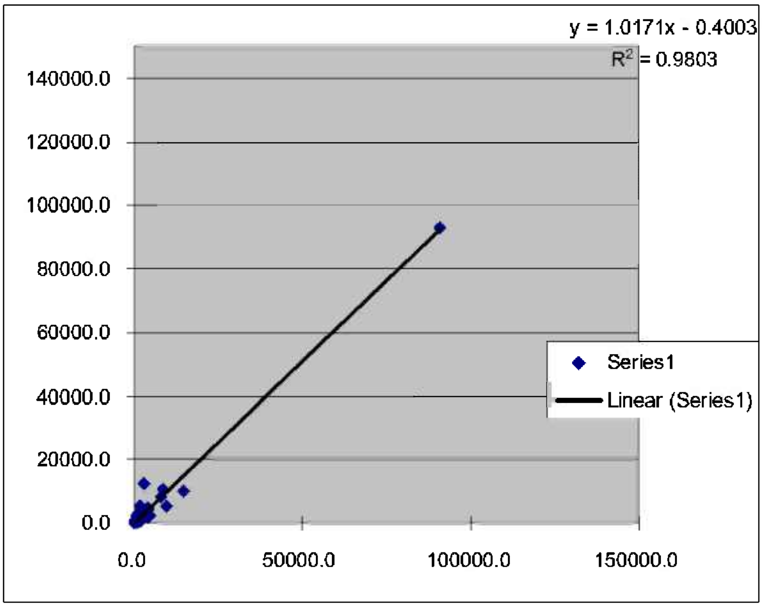


Figure 16. Calibration Results for Daily P Load at Baron Fork near Eldon

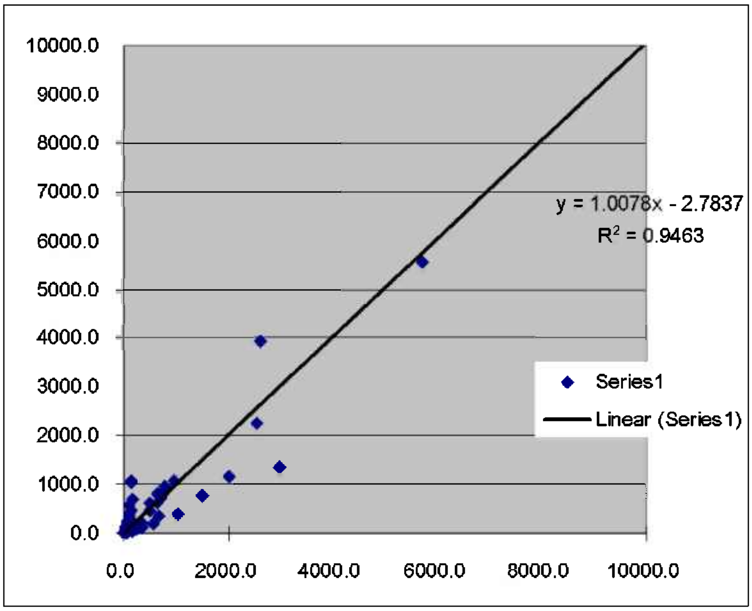


Figure 17. Calibration Results for Daily P Load at Caney Creek

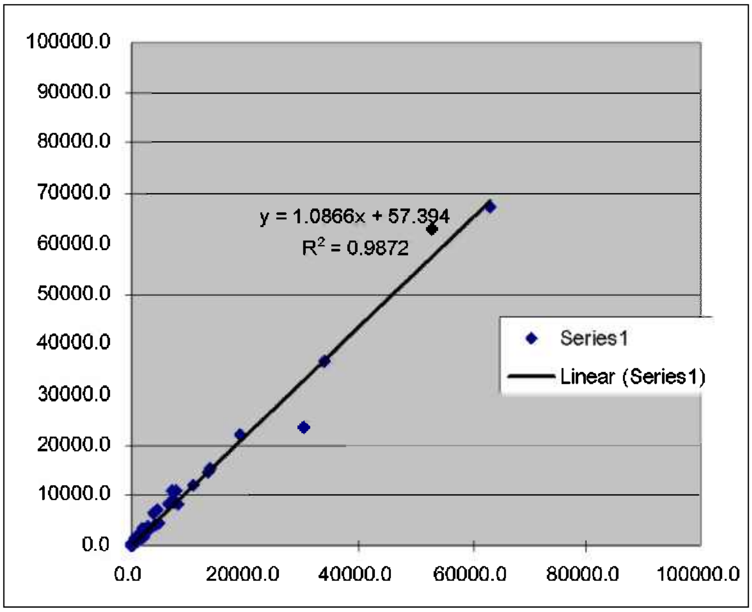


Figure 18. Validation Results for Daily P Load at Tahlequah

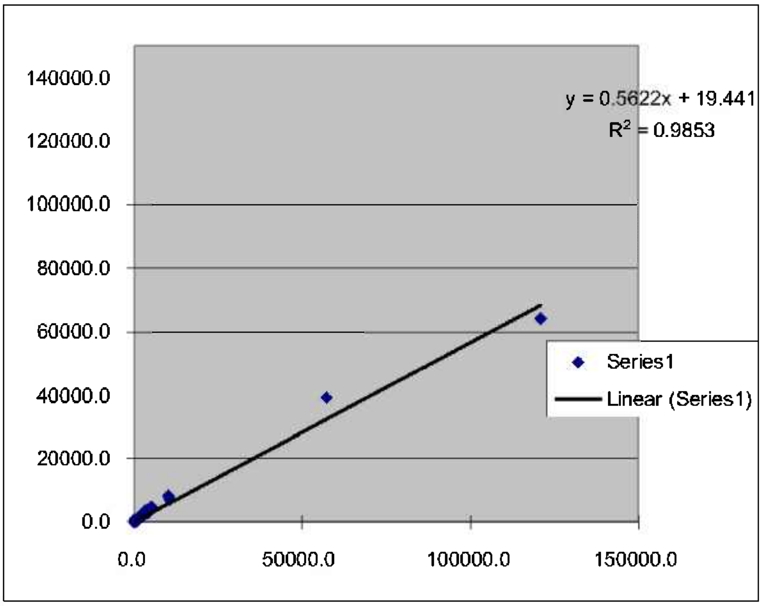


Figure 19. Validation Results for Daily P Load at Baron Fork near Eldon

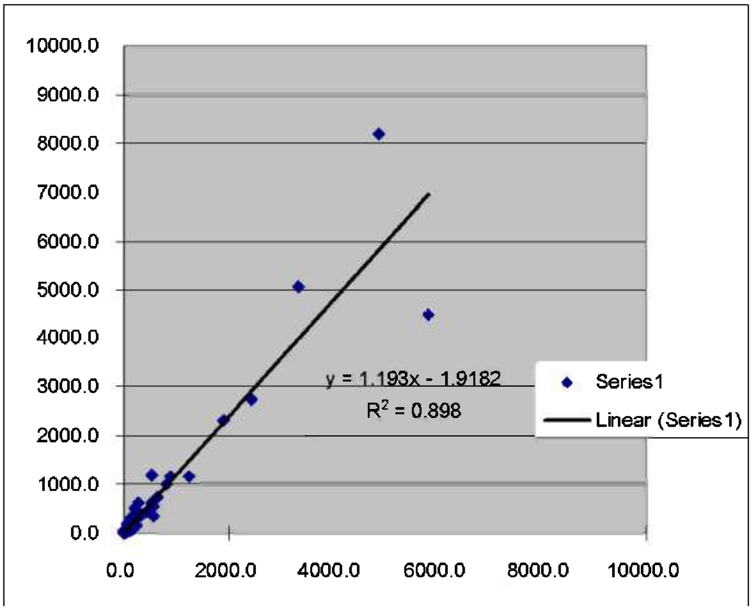


Figure 20. Validation Results for Daily P Load at Caney Creek

The daily Nash-Sutcliffe Coefficients for P load calibration and validation are shown in Table 12. Based on these values and the R^2 values for P loads, the model performs at an acceptable level for use in this project.

Table 12. Nash-Sutcliffe Coefficients (Daily) for P load calibration and validation

Location	**Calibration**	**Validation**
Tahlequah	0.95	0.98
Baron Fork	0.98	0.80
Caney Creek	0.94	0.80

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Modeling Protocol for GLEAMS Application to the Illinois River Watershed

Bernard Engel, Ph.D., P.E.

Problem Definition/Background

Excessive phosphorus loads to the streams and rivers of the Illinois River Watershed (IRW) and to Lake Tenkiller are a concern. Numerous studies have been collected regarding the IRW as described in Engel (2008).

The goals of the hydrologic/water quality modeling of the IRW are to:

1. Quantify phosphorus load magnitudes to streams and rivers in the IRW and to Lake Tenkiller
    a. Historically (1950 to present)
    b. Future scenarios (continued poultry waste application to pastures, cessation of poultry waste application, growth in IRW poultry numbers and corresponding waste application, remediation scenarios)
    c. Background (background soil phosphorus and no poultry waste application)
2. Allocate P loads to the most significant sources

A modeling approach will be needed to complement observed data, prior modeling and analysis as described in various reports on the IRW, and expert opinion. The data documenting historical P loads is limited and modeling provides an opportunity to extend P load estimation spatially and temporally. Modeling will be valuable in predicting various future scenarios for which observed data are not available. The modeling of future scenarios can help identify expected P loads for a range of scenarios. The literature and expert experience provide insight to such scenarios as well and modeling can help conform and further quantify such expert opinions.

Several models have been applied previously to the IRW to determine P loads. Additional details can be found in Engel (2008) and the reports reviewed by Engel. Several studies have used relatively simple modeling approaches that use coefficients based on observed data. Smith et al. (1997) analyzed HUCs (watersheds) to identify the contributors of nutrients to streams and rivers. The Smith et al. (1997) model analysis indicates livestock are responsible for 78.63% of P in the Illinois River while point sources represent 4.5% and fertilizer represents 7.21%. Willett et al. (2006) modeled phosphorus loads from poultry waste application to agricultural areas in the Illinois River Watershed within Arkansas and Oklahoma. In their modeling, 33% of P was available to the crop and 67% went to building P in the soil. Of the P going to the soil, 8% was modeled as lost in runoff. Thus, 5.36% (67% of P to soil * 8% of this lost in runoff) of P applied through poultry litter applications in the watershed was lost in runoff each year (Willet et al., 2006). Nelson et al. (2002) performed a P mass balance for the Arkansas portion of the Illinois River Watershed. They used observed P data in the Illinois River to compute the amount of annual P applied to the landscape that is exported from Arkansas in the Illinois River. Point sources of P were removed from the observed P in the Illinois River before computing the percentage of P that was applied to the landscape that reached the Illinois River and was exported. Nelson et al. (2002) found that 4% of P applied to the landscape in poultry litter, cattle manure, sludge and inorganic fertilizer was lost annually to the Illinois River. If cattle manure is removed from this, as the P contained in cattle manure is recycled P from other sources, this percentage is slightly over 5% which is comparable to the value reported by Willett et al. (2006).

More complex models have also been applied to the IRW. Storm et al. (1996) used SIMPLE (Spatially Integrated Model for Phosphorus Loading and Erosion) in the Illinois River basin. P loading was estimated at 2.30 kg/ha per year (2.05 lb/acre/yr) from pastures after P was applied for 25 years. Storm et al. (2006) used SWAT and a routing model in the IRW and estimated 330,000 kg/yr of total phosphorus (88,000 kg/yr was in soluble mineral forms) reached Lake Tenkiller between 1997 and 2001. The development of a draft TMDL for the IRW and Lake Tenkiller was completed with HSPF which found pasture with poultry waste application responsible for 56% of P loads to Lake Tenkiller (0.90 lb P/acre).

The GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) model was selected for this project due to its ability to describe the hydrologic and water quality processes of importance. One of the strengths of the model is its ability to describe agricultural management systems. In addition, the science within GLEAMS has the same origin of that in SWAT, thus facilitating the potential to use both models without raising concerns about differences in the underlying science.

Model application goals, objectives and hypothesis

The specific objectives of the modeling effort were to:

1. Quantify P loads to the three gauging station locations on streams and rivers closest to Lake Tenkiller (Tahlequah, Baron Fork near Eldon and Caney Creek) for the following:
    a. Historical (1950-1999) conditions
    b. Background (background soil phosphorus and no poultry waste application) – no poultry waste ever in the IRW
    c. Future scenarios
        i. continued poultry waste application to pastures
        ii. cessation of poultry waste application
        iii. growth in IRW poultry numbers and corresponding waste application
        iv. cessation of poultry waste application combined with buffers along streams
2. Allocate P loads to the most significant sources for current conditions

To model future scenarios, weather data representing the 1997-2006 period will be used as this period has the best available data for the IRW and will be used for model calibration and validation. In addition, the rainfall and flows into Tenkiller for this period are variable representing much of the anticipated level of variability that would be expected.

Data for the model scenarios outlined in the modeling objectives will be prepared. Graphs providing comparisons of the results will be created. The continued poultry waste application scenario will provide a basis of comparison for many of the results.

Model selection

The GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) model was selected for this project due to its ability to describe the hydrologic and water quality processes of importance. One of the strengths of the model is its ability to describe agricultural management systems. In addition, the science within GLEAMS has the same origin of that in SWAT, thus facilitating the potential to use both models without raising concerns about differences in the underlying science.

Further details regarding the GLEAMS model can be found in the GLEAMS manual, Lim and Engel (2003), Lim et al. (2006), Mitchell Adeuya et al. (2005), and Thomas et al. (2007).

A model will be required to route P modeled by the GLEAMS model as being lost to streams through the streams/rivers to Lake Tenkiller. Several models were considered for this purpose. A simple empirical approach based on flows in streams and rivers of the IRW and P accumulated in these streams and rivers will be used for routing P loads.

Model sensitivity analysis

The sensitivity of the GLEAMS model to its parameters is well documented in the literature. Dr. Engel has extensive experience in working with GLEAMS based on prior work (Lim and Engel (2003), Lim et al. (2006), Mitchell Adeuya et al. (2005), and Thomas et al. (2007)). The theses and dissertation from which this work was published describe the GLEAMS parameter sensitivity in more detail.

Available Data

Various spatial data are available for the Illinois River Watershed from various sources. The key data include:

1. Elevation data - USGS
2. Land Cover - National Land Cover Dataset (NLCD) for 2001
3. Soil - State Soil Geographic (STATSGO) data

Numerous other spatial data sets for the IRW have been collected and are available from Dr. Robert van Waasbergen.

Weather data for the watershed and surrounding areas are available from the NCDC (National Climate Data Center). The weather stations with the most complete data suitable for use in the IRW are shown in Table 1.

Table 1. Weather stations with data for IRW

	Baron Fork	Illinois River	Caney Creek
Rainfall stations	035354, 348506	032444, 344672, 348677	348506
Temperature station	9450	9450	9450

Streamflow data are available at USGS streamflow gauging stations within the IRW. The gauge locations nearest Lake Tenkiller will be used for the analysis and are listed in Table 2. The period of record for the gauge on Caney Creek is limited in that it starts in October 1997.

Table 2. USGS gauge stations in the IRW nearest Lake Tenkiller

	USGS gage station
Illinois River	USGS 07196500 Illinois River near Tahlequah, OK
Barron Fork	USGS 07197000 Barron Fork at Eldon, OK
Caney Creek	USGS 07197360 Caney Creek near Barber, OK

Phosphorus concentrations in water are available at the USGS gauging stations in Table 2 from the USGS and the OWRB. Beginning in 1998, phosphorus data at these locations were collected for baseflow as well as some storm events. Prior to 1998, efforts were not made to sample storm runoff, and thus nearly all water samples were taken at baseflow conditions. The water samples beginning in 1998 are most appropriate for the modeling effort since the majority of P is moved from the landscape during rainfall events, thus creating nonpoint source (NPS) movement of P. The modeling effort for this project is focused on modeling P movement during rainfall events in addition to daily P movement in IRW streams/rivers to Lake Tenkiller.

Soil Test Phosphorus (STP) data are available from the University of Arkansas and Oklahoma State University. These data can be summarized by county.

Poultry house location and supporting attributes were developed by Dr. Bert Fisher for the IRW.

Poultry waste production and its nutrient content can be computed based on Dr. Fisher's data, Agricultural Census data, integrator poultry data and nutrient content in poultry waste data.

Additional data to be collected

Data quantifying poultry waste amounts and its nutrient content are needed. These will be generated by Dr. Bert Fisher and Dr. Engel. Data describing poultry waste land application patters will be obtained from the literature and analyses to be conducted by Dr. Fisher.

Model representation issues

A P mass balance for the IRW will be completed to identify the important P sources to be considered in modeling. Point and nonpoint sources of P of significance (> 2% of P based on mass balance) will be considered. Point sources (waste water treatment plants) will have the P load directly input to streams and rivers for routing through the streams/rivers to Lake Tenkiller.

The IRW will be divided into hydrologic response units (HRUs) and the GLEAMS model applied to each HRU. This approach is used by other models such as SWAT. Land use and soil data will be intersected in GIS to identify HRUs. GIS elevation and watershed boundary data will be used to subdivide HRUs to place them within subwatersheds.

Individual BMPs within each HRU will not be considered by the model, rather calibration will be used incorporate consideration of BMPs into the modeling effort. The calibrated model will account for existing BMPs. If BMPs are to be modeled in scenario evaluation, these BMPs will be represented as they represent new management efforts.

Some soil parameters will be initially estimated from STATSGO soil properties and then calibrated based on observed runoff and nutrient loss data. These include:

- Effective saturated conductivity
- CN
- Rooting depth
- Depth of bottom of each soil layer
- Soil field capacity
- Soil wilting point
- Soil saturated hydraulic conductivity
- Soil organic matter

The relative values of soil parameters across soils will be linked so it will only be necessary to calibrate one parameter linking soil properties rather than each soil property for each soil.

The parameters most sensitive for calibration of P loads are:
1. CLAB(); Labile phosphorus concentration, ppm, in the soil horizon
2. DF: Date of fertilizer application
3. RATE; Application rate for animal waste
4. APHOS; Total phosphorus content, %, in animal waste
5. APORGP; Organic phosphorus content, %, in animal waste
6. AOM; Organic matter content, %, in animal waste
7. RESDW; Crop residue, kg/ha, on the ground surface when simulation begins

Model Calibration

The hydrology (runoff) will be calibrated first and will use observed flow data at the USGS gauging locations identified in Table 2. The calibration period for hydrology will be 1996-2005 (note data at Caney Creek are not available for all years). The P calibration period will differ as described earlier in this document due to availability of P concentration data in water samples at the gauging sites that represent runoff events. For P, the calibration period will be 1998 through 2002.

Calibration Procedures

An automated calibration approach will be used based on the Shuffled Complex Evolution algorithm approach. This will avoid the potential to bias the model calibration. Hydrology will be calibrated and if results are acceptable, calibration will be extended to P.

Goodness of fit (R^2) and Nash-Sutcliffe coefficients will be used for evaluating calibration success. The runoff calibration will be considered successful if the average monthly R^2 is greater than or equal to 0.60 and the average monthly Nash-Sutcliffe coefficients are greater than or equal to 0.50. For nutrient calibration, values greater than 0.40 for average monthly R^2 and the average monthly Nash-Sutcliffe coefficients will be considered successful.

Model Validation

The runoff validation period will be 1986 through 1995 for the USGS gauging stations identified in Table 2. Note that data are unavailable for this period for Caney Creek. However, Caney Creek contributes little runoff and P to Lake Tenkiller so is far less important than the Tahlequah and Baron Fork near Eldon locations.

The P validation period will be 2003 through 2006.

Average monthly R^2 and the average monthly Nash-Sutcliffe coefficients will be used to assess validation. Values 0.1 less than the calibration success levels will be used to identify successful model validation. If the model performs satisfactorily during validation, it will be applied to model the scenarios of interest.

Model scenario prediction

The calibrated model will be applied to the scenarios identified in the Model Applications section of this document. Continued poultry waste application will serve as the base case for comparison of other modeled results.

Results interpretation/hypothesis testing

A ten year weather cycle will be used in modeling future scenarios (weather and flows from 1997 through 2006). This weather and flow data represent years with rainfall and flow much greater than average as well as years with rainfall and flows much below long-term averages. This 10 year weather cycle will be repeated to model periods longer than 10 years into the future.

Results will be compared to assess the impacts of various scenarios. Appropriate statistical tests will be performed to determine if the P loads for the various scenarios are statistically different.

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Appendix E

Cattle Manure Generation

The amount of cattle manure produced within the IRW was calculated. In addition the amount of P in this manure was calculated. Note that P in the cattle manure is almost entirely P that was deposited within the IRW when poultry waste was spread on pastures (Slaton et al., 2004).

The number of cattle in the IRW was calculated using the 2002 USDA Agricultural Census data and the land uses within the IRW. The census reports cattle numbers by county. To distribute the cattle within counties to the IRW, the amount of pasture within each county was used to perform the distribution in a manner similar to Nelson et al. (2002). Data used in computing manure and P excreted are shown in Table 1. The number of cattle within the IRW by type of cattle is shown in Table 2.

The amount of cattle manure and P produced annually within the IRW is shown in Table 2. Cattle produce approximately 319,000 tons of manure annually on a dry weight basis that contains approximately 7.79 million pounds of P. Note however, that the P contained in this manure is almost entirely from P imported into the IRW for poultry production (Section 7 and Slaton et al., 2004).

Table 1. Data for computing cattle manure and P excreted (from the Agricultural Waste Management Field Handbook)

Cattle Type	P Excreted (lbs/day)	Average Weight (lbs)	Time in Watershed (days)	Manure (dry) (lbs/day)
Beef cows that calved	0.12	1100	365	7.3
Dairy cows	0.07	1300	365	10
Other cattle	0.07	650	365	7.3
Calves and cattle sold	0.07	500	300	7.3
Calves	0.03	300	240	7.3

Table 2. Number of cattle within the IRW by type of cattle as calculated from 2002 Agricultural Census data and IRW land use data

Cattle Type	Number in Watershed	P (lb/yr)	Waste (tons/yr)
Beef cows that calved	101,367	4,883,857	148,551
Dairy cows	10,280	341,455	24,390
Other cattle	81,535	1,354,094	70,606
Calves and cattle sold	98,455	1,033,782	53,904
Calves	81,481	175,999	21,413
Total		7,789,186	318,864

Appendix F

Contribution of Cattle in Streams to P Loads in the Illinois River Watershed

Cattle standing in or near streams and defecating in these areas make phosphorus (P) more readily available to water in the streams than would be the case if they were fenced from these streams. Although the P excreted by cattle in the Illinois River Watershed is P initially placed in the watershed through the production of poultry, some of these cattle have access to streams and deposit some P in or near the streams. The amount of P deposited in or near streams (within 10 meters) was estimated following a procedure described below. ***Cattle P deposited in or near streams represents 6% of the annual P loads to Lake Tenkiller.***

Cattle in the Illinois River Watershed

The number of cattle in the watershed was estimated based on the 2002 Census of Agriculture and the Illinois River Watershed (IRW) land use data. The number of cattle in each county that were also within the IRW was estimated based on the percentage of pasture within a county that was within the IRW and the census estimate of cattle in the county. A similar allocation approach was used by Nelson et al (2002).

The number of cattle within each of the counties within the IRW as reported in the 2002 Census of Agriculture are shown in Table 1. The portion of each county's pasture that is within the IRW is shown in Table 2. Estimates of the number of cattle by type within the IRW were obtained by multiplying the data from Tables 1 and 2. The results are shown in Table 3.

Table 1. USDA 2002 Census of Agriculture Cattle in Illinois River Watershed Counties

Cattle Type	Adair	Benton	Cherokee	Delaware	Sequoyah	Washington
cows that calved (included in cattle and calves)	35554	64383	27709	43146	22199	63281
beef (included in cows that calved)	28028	60948	25333	40089	22126	60753
cattle and calves	59033	113588	45573	74719	37889	112650
other (included in cattle and calves)	23479	49205	17864	31573	15,690	49369
cattle and calves sold	34,174	54172	25,183	40,251	23,453	52811
calves < 500 sold	13,574	25514	8,927	14,450	8,061	26950
calves and cattle > 500 sold	20600	28658	16256	25801	15392	25861
dairy (included in cattle and calves)	7526	3435	2528	3057	73	2528
cattle on feed (included in cattle and calves)	101	944	192	219	530	651

Table 2. Portion of pasture within each county in IRW

County	Portion of Pasture in Watershed
Adair	0.799
Benton	0.450
Cherokee	0.356
Delaware	0.090
Sequoyah	0.085
Washington	0.610

Table 3. Cattle in the IRW

Cattle Type	Number in Watershed
Beef cows that calved	101367
Dairy cows	10280
Other cattle	81535
Calves and cattle sold	98455
Calves	81481

Cattle with Access to Streams

The cattle with access to streams were calculated by performing a capture zone analysis within GIS to identify pastures with stream access and estimating the number of cattle within these pastures. Pasture sizes were identified from ODAFF records that identified the size of pasture on which poultry waste was spread. Pastures were assumed to be square and were assumed to randomly intersect streams and rivers within the IRW. Using the pasture sizes, capture zone (or buffer) distances to use along streams and rivers for identification of pastures with access to streams and rivers were computed. The distances were 522 ft, 582 ft, 617 ft, and 660 ft. Pasture within each of these distances from 3rd order and larger streams (streams that typically have water) were identified (Table 4). Cattle by various types were assumed to be uniformly distributed within these pastures (Table 5).

Table 4. Area of pasture within capture zone distance of Third order and higher streams in the IRW

Pasture Area by Zone (acres)			
522 ft	582 ft	617 ft	660 ft
24,548	27,575	29,449	31,494

Table 5. Cattle density in IRW pastures and number of cattle by capture zone distance

		522 ft	582 ft	617 ft	660 ft
Cattle Type	**Density (animals/acre of pasture)**	**Number of cattle**	**Number of cattle**	**Number of cattle**	**Number of cattle**
Beef cows that calved	0.210	5154	5790	6183	6613
Dairy cows	0.021	523	587	627	671
Other cattle	0.169	4146	4657	4974	5319
Calves and cattle sold	0.204	5006	5624	6006	6423
Calves	0.169	4143	4654	4970	5315

Not all pastures provide access to streams or rivers within the IRW. Ed Fite indicated between 40 and 50% of pastures that would touch streams or rivers within the IRW fence cattle from the stream or river.

Cattle P in and Near Streams
James et al. (2007) observed cattle in and near streams and determine the amount of waste excreted in these areas and the amount of P in cow patties. They found that cattle excreted approximately 0.0076 lb/day of P in or within 10m of streams. Gary et al. (1983) observed cattle in and near streams and found that 8% of cattle excrement was deposited in or within 10m of streams. Using 8% of waste, P in cattle waste from the USDA Waste Characteristics Handbook, and assuming 1000 lb cattle, the daily P deposited in or near streams (within 10m) is 0.0096 lb/day.

Using a daily P deposited value of 0.0096 lb/day, the cattle with potential access as shown in Table 5, and assuming 45% of cattle with potential for access are fenced from the stream or river, the annual P deposited in or within 10m of streams was computed as shown in Table 6. Cattle were assumed to preferentially prefer defecating in or near streams year around. In reality not all cattle have access to streams throughout the year nor do they preferentially prefer to be near streams in cooler periods of the year. Thus, the estimates of P excreted in Table 6 overestimate the P actually deposited in these areas.

Table 6. Estimated P deposited by cattle in and near (within 10m) of streams in the IRW

	P (lb/yr)			
Cattle Type	**522 ft**	**582 ft**	**617 ft**	**660 ft**
Beef cows that calved	11920	13390	14300	15293
Dairy cows	1209	1358	1450	1551
Other cattle	4794	5385	5751	6150
Calves and cattle sold	6946	7803	8333	8912
Calves	2874	3229	3448	3688
Total	27743	31165	33283	35594

To put the P estimates from Table 6 in perspective, the average annual P observed at the three gauging stations closest to Lake Tenkiller (Tahlequah, Baron Fork and Caney Creek) between 1998 and 2006 (years with the most complete P data) is slightly less than 500,000 lbs. Cattle P deposited in or near streams would represent 6% of the annual P loads to Lake Tenkiller.

References

Gary, H. S. Johnson, S. Ponce. 1983. Cattle grazing impact on surface water quality in a Colorado Front Range stream. Journal of Soil and Water Conservation 38(2):124-128.

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Appendix G

Potential Septic Tank Contribution

An analysis was conducted to estimate the potential P inputs into the highflow watersheds based on human populations. Properly functioning septic systems would allow no or very little P to be discharged into the streams within these watersheds. The Oklahoma Department of Environmental Quality (1997) investigation of septic systems in the Illinois River concludes "systems identified in this study were found to pose no apparent significant threat to the quality of the Illinois River."

P loads to septic systems within each of the highflow watersheds were computed based on the number of houses identified from aerial photos within each watershed, household size from the census, and P excreted per person from a literature source. P exports from these watersheds were estimated for a small number of runoff events and baseflow from 2005 and 2006.

Estimated P exported from the watersheds for the runoff events sampled and from baseflow greatly exceeded P loads to septic systems for most of the watersheds (Table 1). ***Based on this analysis and the Oklahoma Department of Environmental Quality report on septic systems, the septic systems in the highflow watersheds are not the primary source of P exports in runoff and baseflow.***

2.49 people/household in Arkansas from http://quickfacts.census.gov/qfd/states/05000.html

2.49 people/household in Oklahoma from http://quickfacts.census.gov/qfd/states/40000.html

1.1 lb P per person per year (Sarac et al., 2001)

P contribution per household per year
2.49 people * 1.1 lb/person = 2.74 lb per household per year

Table 1. P loads from sub-basins compared to human P in sub-basins

Site ID	2005 baseflow P (kg)	2006 baseflow P (kg)	2005 highflow P (kg)	2006 highflow P (kg)	Annual Human P (kg)
HFS 02	7.348942	34.45084	369.8509	357.2	236.9436
HFS 04	0	0	0	0	244.2534
HFS 05	5.157429	16.03391	1165.365	375.06	204.5985
HFS 08	0.670428	0	371.9345	0	196.241
HFS 14	0.063186	0	95.10451	142.88	16.64032
HFS 16	0.343191	0.080233	133.4142	2.4111	21.35549
HFS 20	0.327493	1.83129	74.34226	19.646	45.46773
HFS 21	0.081386	20.34333	0	40.185	77.23901
HFS 22	0	0	0	0	65.31386
HFS 23	78.45195	24.6948	250.04	371.488	578.3071
HFS 26	0.0221	0	154.0425	0	25.12264
HFS 28A	0	3.977095	103.1415	3.572	17.71308
HFS 29	0	1.900684	0	25.004	52.61533
HFS 30	0	15.15998	0	178.6	28.72762

References

Sarac, K., A. Kohlenberg, L. Davison, J.J. Bruce, and S. White. 2001. Septic System Performance: A Study at Dunoon Northern NSW. On-site '01 – Advancing On-site Systems Conference: University of New England, Armidale, NSW, 25-27 Sept, pp: 323-330.

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